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THESIS

AUTOMATIC IDENTIFICATION TECHNOLOGY: TRACKING WEAPONS AND AMMUNITION FOR THE NORWEGIAN ARMED FORCES

by

Tord Hjalmar Lien

June 2011

Thesis Advisor:	Geraldo Ferrer
Second Reader:	Tali Freed

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A case study for the NAF is conducted where processes and objectives that are important for the inventory system are presented. Based on the specific requirements in the NAF's inventory system, an analysis of four different inventory management solutions is examined. For the RFID solution, an experiment is conducted to determine whether this is a feasible solution for small arms inventory control.

A recommendation is formed based on the results of this analysis. The tandem solution, which uses IUID technology at the item level, passive RFID at the box level and active RFID when items are transported, is the recommendation. This solution uses the appropriate technologies where they are best suited and offers the best results for an accurate inventory control system with low implementation costs and risks.

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AUTOMATIC IDENTIFICATION TECHNOLOGY: TRACKING WEAPONS AND AMMUNITION FOR THE NORWEGIAN ARMED FORCES

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Submitted in partial fulfillment of the
requirements for the degree of

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LIST OF ACRONYMS AND ABBREVIATIONS

2D	Two-Dimensional
AEN	Ambient Electronic Noise
AIT	Automatic Identification Technology
Auto ID	Automatic Identification of a Physical Object.
AWA	Attractive Weapons and Ammunition program
CCD	Charge Coupled Device
DoD	United States Department of Defense
EPC	Electronic Product Code
ERP	Enterprise Resource Planning
GHz	Giga Hertz
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communications
HF	High Frequency
Hz	Hertz
IUID	Item Unique Identification
KHz	Kilo Hertz
LED	Light-Emitting Diode
LF	Low Frequency
MHz	Mega Hertz
MIT	Massachusetts Institute for Technology
MTBF	Mean Time Between Failures
NAF	Norwegian Armed Forces
NDLO	Norwegian Defense Logistics Organization
RF	Radio Frequency
RFID	Radio Frequency Identification
RO	Read Only
RW	Read & Write
UHF	Ultra High Frequencies
UID	Unique Identification

UPC	Universal Product Code
U.S.	United States
USMC	United States Marine Corp
WORM	Write Once, Read Many

I. INTRODUCTION

The value of an assault rifle is not something that can be measured in terms of dollars. Armed forces and police forces are allowed to carry and use weapons as a tool of power. With this privilege comes great responsibility; these weapons need to be under strict control and not available to criminals or others whose intentions are unknown.

In 2004, criminals robbed a Norwegian bank and killed a police officer. The robbers used weapons that had been stolen from the Norwegian Armed Forces (NAF). Due to incidents like this, and reports from audits of the armed forces, a mandate to improve the accountability and security of small arms inventories in the NAF was created. One of the initiatives was to implement electronic asset tracking technology to improve inventory accuracy of small arms and lower the transaction costs when small arms change location or ownership.

Automatic Identification Technology (AIT) has flooded private industries in the last twenty years. Barcodes, Item Unique Identification (IUID) and Radio Frequency Identification (RFID) are commonly used to increase the efficiency of supply chains all around the world. Big global players like Wal-Mart and the U.S. Department of Defense (DoD) have pushed on and added speed to the introduction of new technology.

Implementing new technology is always a challenging and important phase for an organization. The decision on which technology should be implemented and how it will be implemented must be based on thorough analyses of how the technology will improve the process and what it will cost. Many possible alternatives must be examined before a decision is made.

The goal of this thesis is to examine IUID and RFID technologies, identify their benefits and challenges, and compare them with each other. The second part of this thesis is a case study that describes in detail how RFID and IUID can be used as part of the Attractive Weapons and Ammunition program (AWA). The author describes how active RFID can be used to monitor the transport of high value items for the NAF, and through tests determine whether RFID is a feasible AIT for the main assault rifle in the NAF.

Since AIT has a huge economical impact in today's private sector, there is a wide range of literature available on the topic, but due to the relative young age of the technology there are not many empirical studies of actual results of implementation.[1]

This thesis uses available literature to give the reader a technical understanding of how RFID and IUID work, and to understand the limitations and possibilities of the technology. The RFID Sourcebook (Lahiri) and the article "Understanding RFID and Its impact on the Supply Chain" (Maloni and DeWolf) are prime sources in the RFID chapter, while the books Optimizing Processes with RFID and Auto ID (Bartneck, Klaas and Schoenherr) and UID Journal Workbook (Bensman) are central in describing IUID technology.

For small arms, specifically, there exists a report on how the British Police Force implemented RFID on its small arms inventory, and in 2008 three students from the Naval Postgraduate School examined how IUID had been implemented for the United States Marine Corps (USMC) small arms inventory. Both these reports are used to cast light over this research.

Costs saving improvements in the supply chain are important because they directly improve the results on the bottom line. Cost-benefit analyses or return on investment calculations are often conducted to determine whether an investment should be made; however, for the NAF the bottom line results are not the most important measure. The cost to the Norwegian society, if their armed forces do not control their weapons, is much graver than the monetary value of the rifles that are lost.

Funds have already been approved and allocated to conduct this project; therefore this thesis does not focus solely on the acquisition cost of the technology. Factors like accountability, complexity, and durability all influence the total life cycle costs of the system that establish the basis of the recommendation.

Chapter II is a quick introduction to AIT that provides history and background for the topic. In chapter III RFID technology is described in detail and popular applications

[1] E.W.T Ngai, Karen Moon, Fredrik Riggins and Candace Yi," RFID research: An academic literature review (1995-2005) and future research directions," Int. J. Production Economics 112 (2008): 515.

of RFID are covered; Chapter IV does the same for IUID technology, and both chapters conclude with a summary of the benefits and challenges linked to each technology. Chapter V places the theory from the preceding chapters into a real-life application, and discusses how the NAF can implement AIT in the AWA program. Testing is conducted to determine whether RFID technology is suitable for tagging metallic items like an assault rifle.

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II. AUTOMATIC IDENTIFICATION TECHNOLOGY

A. BACKGROUND, HISTORY AND DEVELOPMENT

Ever since mankind developed the ability to communicate, people started giving names to things. By naming objects people were able to increase the value of their communications and provide useful information to each other. As the Industrial Revolution changed the way products and services were provided, the need for more specific identification of objects and products developed. Mass production and larger markets for products created an increased interest in the accuracy of identifying individual items.

The advent of computer technology and the automation of industrial processes provided tools needed to develop more sophisticated and improved ways to mark and recognize products. Based on the work done by great scientists in the nineteen century like Maxwell, who pioneered radio technology and improvements of optical systems, the possibilities began to reveal themselves.[2] RFID was first used in a friend or foe identification system by the British during the Second World War,[3] and Wrigley marked their first product with a barcode that could be machine read in a supermarket in 1974.[4]

Since then, the use of AIT has exploded, and it is hard to imagine an advanced society without it. As both private and public services saw the benefits the technology could provide, the resources used on developing new and improved technology have increased the number of applications, improved quality and lowered the costs of using the technology.

The ultimate objective for proponents of AIT is to create an "Internet of things," where companies can have full visibility of their products from start of production,

2 Norbert Bartneck, Volcker Klaas and Holger Schoenherr, Optimizing processes with RFID and Auto ID, (Publics publishing, 2009), 15.

3 Ibid., 16.

4 Katina Michael and M. G. Michael, Innovative Automatic Identification and Location-Based Services, (IGI Global, 2009), 91.

through their supply chain, and to consumers; thus, the ability to follow the product throughout its life cycle.[5] RFID, for example, has the potential to provide real-time information about the exact location, contents, history and the conditions materials are in, all within one system.

Obviously, there are critics of this scenario; consumer advocates are concerned that the technology can be misused. Firms can use it to track the location of products after they are sold, and thereby conflict with personal location privacy. An example is information collected when passing through an automatic toll road that can be collected and used for other purposes. For companies that use the technology, there are security concerns that competitors can access and gather confidential data stored on tags. This has led to increased interest in encryption of the information on the tags.[6]

Today, barcodes are the most commonly used AIT. Seventy-five percent of the products that use AIT today use optical codes like barcodes,7 but the inherent limitations of this technology open the doors for new technologies to dominate AIT markets in the future. Bluetooth is now used as a wireless substitute for transfer of data between electronic products, but security issues have slowed down its impact on supply chain applications.[8] The use of second-generation barcodes called 2D matrix codes has already proved its value and is implemented in a large scale. A mandate by the U.S. Department of Defense (DoD) has forced its suppliers to quickly adopt this technology if they want to do business with the military. RFID is the other big emerging choice of AIT; RFID can communicate information without having line of sight with the product itself.

The next two chapters discuss the last two mentioned technologies, RFID and IUID, describe how they work and what the major challenges and benefits with them are.

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[5] E. W. T Ngai et al.,” RFID research: An academic literature review 510.

[6] Ibid., 513.

[7] Norbert Bartneck, Volcker Klaas and Holger Schoenherr, Optimizing processes with RFID and Auto ID, 14.

[8] Simon Garfinkel, Beth Rosenberg, RFID, Applications, Security, and Privacy (Pearson Education Inc., 2006), 306.

III. RFID

Radio Frequency Identification (RFID) uses radio waves to identify objects. RFID can be described as a technology that allows objects to be identified at a distance without direct line of sight and using an electromagnetic challenge/response exchange.[9]

Using Radio Frequency technology as an AIT requires a system of components that are tuned perfectly to each other to give the desired results. The RFID system offers a wide range of options that are not available with other AITs. Figure 1 shows a diagram of all the parts that must connect to enable an RFID System to operate.

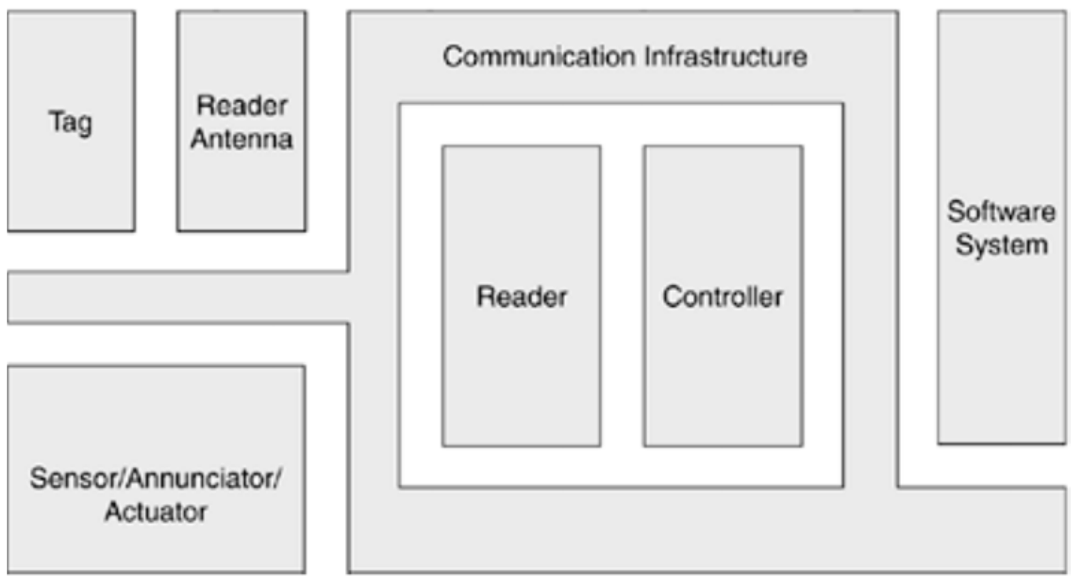

Figure 1. Components in an RFID System.[10]

[9] Katina Michael and M. G. Michael, Innovative Automatic Identification and Location-Based Services, (IGI Global, 2009), 235.

[10] Sandip Lahiri, RFID Sourcebook, (IBM Press, 2006), 7.

The following steps explain, in a simplified way, how an RFID system that uses passive tags works:[11]

1. The tag is activated when it passes through a radio frequency field that has been generated through a reader and an antenna.
2. The tag use energy from the radio frequency signal it receives and sends out a preprogrammed response to the reader.
3. The antenna and reader that originally sent out the signal detects the response and collects it.
4. The reader sends the information collected from the tag to the middleware.
5. The middleware interprets the information and sends it to the final inventory management system where the data can be monitored and analyzed.

Even when one has the right components available, RFID is not a plug-and-play system. The use of radio waves implies that each system must be tailored specifically to each location it is to be used in. In addition, the substance of the item that is marked influences how the radio waves react and the quality of the communication. This gives implementers two options: buy the service from third-party suppliers or increase their own knowledge of what is needed to succeed.

The MIT Auto-ID Center has been instrumental in creating worldwide accepted standards for RFID technology,[12] and this has been important in the development of RFID and to guide the use of RFID technology. Their Electronic Product Code (EPC) protocol has been accepted worldwide as the standard to use for RFID. Uniform Product Code (UPC), which is the standard for barcodes, offers thousands of options. The EPC, on the other hand, utilizes the increased memory possible to store in an RFID tag and offers the opportunity to individually mark trillions of unique items. Along with other big drivers like the DoD and Wal-Mart, the Auto ID Center has been important in leading the development within the field.

[11] Patrick J. Sweeney II, *RFID for Dummies*, (Wiley Publishing, 2005), 78.

[12] Michael Maloni and Frank DeWolf, “Understanding Radio Frequency Identification (RFID) and Its Impact on the Supply Chain,” (2006): 5.

The following part of this chapter explains how each of the components in the RFID system work, how it reacts to different environments, and how materials influence the system. All of this is essential information when implementing a properly working RFID system.

A. TECHNOLOGY

1. Tags

The tag in an RFID system is the device that is attached to the item that one wants to identify. There are three main types of tags available: passive, active and semi-passive. Within these types different suppliers offer a wide range of different alternative configurations to fulfill requirements. Range, accuracy, longevity, size and attachment criteria determine the options. In addition, some tags are preprogrammed by the suppliers and cannot be changed. These tags are called Read Only (RO) Tags. Others tags offer the opportunity to write one's own data on the tag, but the information cannot be changed once it is written. These tags are called Write Once, Read Many (WORM) tags. The most flexible and expensive tags can be reprogrammed and rewritten many times; these tags are defined as Read Write (RW). The great possibilities offered by RW tags might also be a security concern. It might be possible for competitors to reprogram the tags in a way that does not benefit an organization. Tags are also divided into generations and classes based on their characteristics. As an example, a Generation 2, Class 3 tag is a semi-passive or battery-assisted tag.[13]

Passive tags are the most popular choice by users of RFID today, as they offer a low price per tag, a long life, and are resistant to harsh environments. Figure 2 shows the main components in a passive tag.

[13] Albert Lozano-Nieto, RFID Design Fundamentals and Applications (CRC Press, 2011), 7.

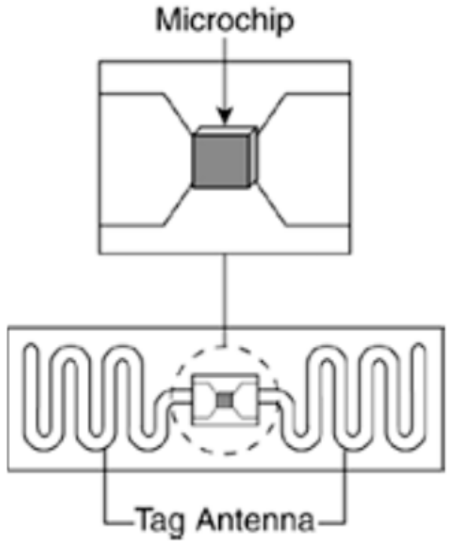

Figure 2. Components in a Passive RFID Tag.[14]

As seen in Figure 2, there is no battery in the tag. Passive tags collect energy transmitted from the reader antenna and harvest this energy through backscatter modulation where it converts airborne energy to direct current. This current is used by its microprocessor to communicate its own preprogrammed response that it transmits through its antenna to reply to the approach from the reader. The passive tag only broadcast when it is awoken by a reader antenna. The design of the antenna used in a tag varies greatly. Its size and pattern must be adjusted to the frequencies that are used, and specific designs work better when used on different types of materials. A small loop antenna, seen in Figure 3, has proved to work well with metallic materials as it utilizes the electromagnetic fields that are present near metallic surfaces.[15]

[14] Sandip Lahiri, *RFID Sourcebook*, 10.

[15] Mun L. NG, Kin S. Leong, and Peter H. Cole, "RFID Tags for Metallic Object Identification" (Taylor & Francis Group 2007): 255.

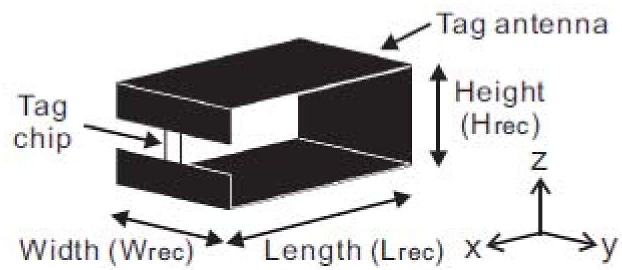

Figure 3. RFID Tag with Small Loop Antenna.[16]

The pictures in Figure 4 and Figure 5 show some of the alternatives that are available within passive RFID tags.

Figure 4. Passive RFID Tag Embedded in Label.[17]

[16] Mun L. NG, Kin S. Leong, and Peter H. Cole, "RFID Tags for Metallic Object Identification," (Taylor & Francis Group 2007): 255.

[17] "Passive RFID tag embedded in label," accessed February 23, 2011, http://www2.cpttm.org.mo/cyberlab/rfid/intro.html.en.

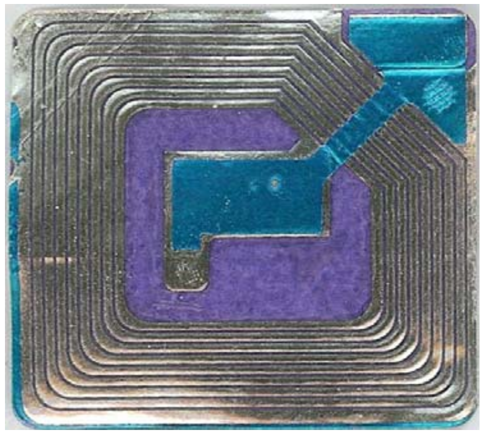

Figure 5. A Close-up of a Passive RFID Tag.[18]

The main difference between a passive and an active tag is that while the passive tag uses energy from the reader antenna, the active tag contains its own power source. This power source, usually battery but solar is also possible, give more possibilities in what the tag can do. The range can improve greatly, and tags can be read up to one hundred meters away. It can also support a sensor system where the tag can communicate information about the conditions where it is located; temperature, humidity and motion detectors are just some examples of sensors that can be attached. The costs of these tags are significantly higher and their longevity is limited by the battery life. To increase the life of the tag, it is possible to program it so that it only transmits when it is awoken by a signal from a reader antenna. This also reduces the amount of Radio Frequency (RF) noise in the environment. The content of an active tag is similar to a passive tag, but battery and sensors that are added means that the size of an active tag is usually larger. Autopass tags used for passing toll roads are examples of commonly used active tags.

[18] "Passive RFID tag with antenna," accessed February 23, 2011, http://www.consumerwarningnetwork.com/wp-content/uploads/2008/11/rfid_tag_blue_security.jpg.

Figure 6. Active RFID Tag with an External Antenna. Range According to the Supplier is up to 1.5 km.[19]

A semi-active tag includes internal batteries and can support sensors. It uses its internal battery to support the sensors and memory but harvests energy from the reader antenna to transmit the signals. This means that a semi-active tag can be read from longer distances than passive tags, and its response time is quicker, as it does not use airborne energy to excite its own memory chip.[20] Savi Technology, a California-based supplier of RFID solutions, unveiled a new development in active tag assortment in 2009 with a hybrid tag called the ST-694 Global Tag.[21] The tag combines RFID, satellite communication and Global Positioning System (GPS) technologies. Due to inherent limitations in active RFID tags, the maximal reading range of a regular active tag is restricted. This implies that interrogators must be placed in the supply chain to gather information from the tags. These interrogators can cost from $500 to $2000 per piece depending on the specifications, and they need a communication infrastructure to connect with the Enterprise Resource Planning (ERP) system and maintenance and monitoring to ensure that they work as programmed. With the ST-694 Global Tag this limitation is recognized; therefore, this hybrid tag offers a range of different communication options. All communication and sensor systems are controlled by the microchip in the active tag,

[19] "Active RFID tag with external antenna from Sebine Technologies," accessed February 16, 2011, http://www.gobizkorea.com/blog/ProductView.do?blogid=sebinetech&id=945515.

[20] Sandip Lahiri, *RFID Sourcebook*, 17.

[21] Beth Bacheldor. "Hybrid Tag Includes Active RFID, GPS, Satellite and Sensors," RFID Journal, 24 February 2009.

and the system can automatically determine the communication means that are available. If the tag is in the proximity of a RFID integration field, it will use the RFID, and if not, it will link up with a satellite system.

2. Frequencies

The one characteristic that makes RFID stand apart from other AITs is that it uses radio waves to communicate. This offers superior advantages, but also makes the system more complex. To understand how it works, the fundamental concepts of radio frequencies must be explained. An electromagnetic wave, as seen in Figure 7, is created by electrons in motion; these waves of electrons can pass through a number of different materials.

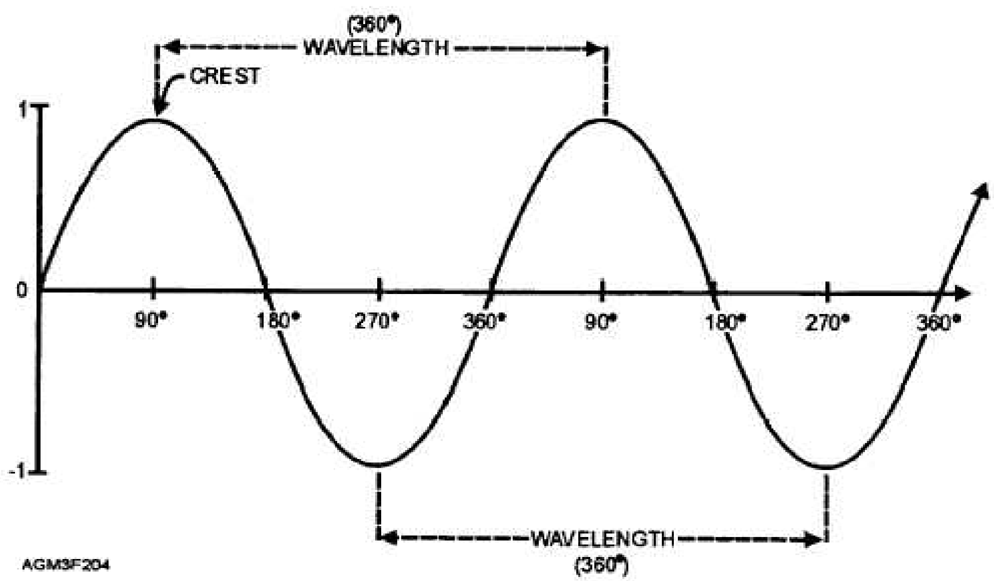

Figure 7. Wavelength in an Electromagnetic Wave.[22]

To measure the frequency of a wave, the time between each crest of the wave is measured. This frequency is measured per second or hertz (Hz). If a frequency moves

[22] "Wavelength in an Electro Magnetic Wave," accessed February 14, 2011, http://www.tpub.com/content/aerographer/14271/css/14271_55.htm.

with 1 Hz, it means that it takes one second for a wave to reach its next crest. Radio waves, which are the ones that will be discussed here, have frequencies between 30 Hz and 300 gigahertz (GHz).[23]

Choosing which frequency to use is important because there are different characteristics both in how they react with materials and in what range the different frequencies will work. Some materials are RF-opaque; they block, scatter and reflect RF waves. Other materials are defined as RF-absorbent, and they absorb the energy and allow only parts of it to pass through.24 Table 1 gives an overview of how different materials react with frequencies.

Material	LF	HF	UHF	Microwave
Clothing	RF-lucent	RF-lucent	RF-lucent	RF-lucent
Dry wood	RF-lucent	RF-lucent	RF-lucent	RF-absorbent
Graphite	RF-lucent	RF-lucent	RF-opaque	RF-opaque
Liquids (some types)	RF-lucent	RF-lucent	RF-absorbent	RF-absorbent
Metals	RF-lucent	RF-lucent	RF-opaque	RF-opaque
Motor oil	RF-lucent	RF-lucent	RF-lucent	RF-lucent
Paper products	RF-lucent	RF-lucent	RF-lucent	RF-lucent
Plastics (some types)	RF-lucent	RF-lucent	RF-lucent	RF-lucent

Table 1. Material Characteristics in Different Frequency Areas. [25]

The frequencies used for RFID are divided in four categories: low, high, ultra high and microwave frequencies. Each of these has different characteristics and applications where they are suited. The exact environment where they are used and the materials that are in that area directly determines the efficiency of the signals that are transmitted. The low frequencies use the radio waves between 30 KHz and 300 KHz, and have low transfer rates from the tag to the reader. They are especially good when used in environments that contain metals, liquids, dirt, snow and mud. The reading ranges offered by low frequencies are short, and it reads just beyond actual contact.

[23] Sandip Lahiri, *RFID Sourcebook,* 3.

[24] Ibid.

[25] Ibid., 6.

High frequencies range from 3 MHz to 30 MHz, and have slow transfer rates from the tag to the reader. They are more likely to be interfered with when used in an environment that contains metals or liquids. The reading range is limited to around a foot. High frequency systems are extensively used in environments that rely to a large extent on other RF transmitting equipment, like hospitals, because they do not interfere with other RF transmissions.[26]

The Ultra High Frequencies (UHF) tag uses the range from 300 MHz to 1 GHz; they have a fast transfer rate and work in longer distances than the two previous frequency areas. Parts of the spectrum in UHF perform badly in the presence of metals or liquids, but there are areas in this field that are not severely affected by the materials. The reading range offered in this frequency can be up to 100 meters when used with active tags. The use of the UHF range is not accepted worldwide, so to determine which frequencies that are available the user must check with local authorities to find out if they are allowed to use them.[27]

Microwave frequencies use the frequency area above 1 GHz. They work both with passive and active tags and have the fastest data transfer rate between the tag and the reader of all frequency types. The tags in a microwave system can be very small, as the antenna needed to collect the signals can be short. Microwaves perform poorly when metals or liquids are present in the environment of the system.[28]

3. Readers and Antennas

The reader and the antennas that are connected to tags control and initiate the communication with them. Through its antenna, the reader sends radio signals to activate tags within its range and listens and receives replies from tags that answer. The main parts in this system are antenna, receiver, transmitter and a microprocessor that reads and interprets the information. Some readers also have the ability to write new information onto RW tags.

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[26] Sandip Lahiri, *RFID Sourcebook*, 4.

[27] Ibid.

[28] Ibid., 5.

The reader's antenna is connected to the reader through a coaxial connection, and even though the exact placement of the reader is not important, the choice of where to position the antenna is essential for the results of the communication. Directivity, gain and polarization are important parameters for when to determine antenna type and how to install it. Directivity influences in which direction signals are transmitted and received. Gain controls how energy is focused within the direction, and polarization describes the orientation of the waves that are transmitted.[29] Linear antennas transmit in vertical or horizontal straight lines that allow for long range but the signals transmitted are narrow, so to be successful they must be aimed precisely at the tags. The straight lines are also better able to penetrate RF-absorbent materials. Circular waves have shorter ranges, but allow for a wider signal to be transmitted. This allows for greater flexibility in where the tags are and how they are oriented.[30] Figure 8 shows the area that this particular antenna can penetrate; however, local conditions will influence the actual results produced by this antenna.

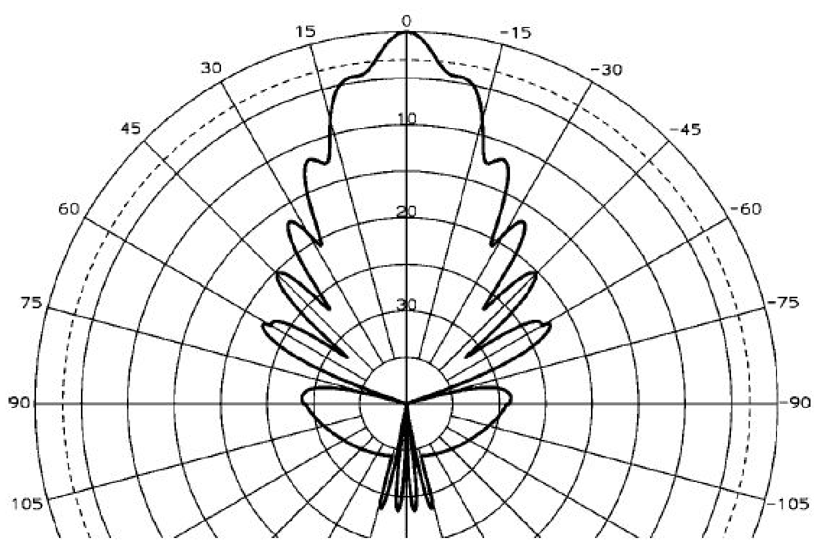

Figure 8. Image of the Reading Pattern of an Antenna from AnteTec.[31]

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[29] Patrick J. Sweeney II, *RFID for Dummies*, 99.

[30] Michael Maloni and Frank DeWolf, "Understanding Radio Frequency Identification (RFID) and Its Impact on the Supply Chain," (2006): 8.

[31] "Reading range of RFID antenna from AnteTec," accessed February 27, 2011, http://www.antetec.com/news/2010/03/25-415.html.

4. Software

Software in this perspective is the program that controls the hardware in the RFID system and transforms the signals so that they can be interpreted by the organization's ERP system.[32] In RFID terminology, it is often called middleware because it works between the information gathering equipment and the user interface that is used. Readers and devices are controlled by the middleware and adjustments on the system are made through it. The middleware translates the signals captured by the reader into EPC numbers that are sent to the ERP system, and it can also be linked directly to third party systems so that they get instant access to the information. This can be used to inform suppliers about the need to resupply a certain stock item when supplies are running low.

When deciding on which middleware to use and how to set it up, several considerations must be made. The complexity of the system influences how much flexibility the system must be able to handle. A fixed setup that does not need to change much does not have to include advanced options for the users. Systems that only need to communicate with one external database system are less demanding than a middleware system that needs to communicate with several internal and external systems. For the setup of the middleware, it is important that the user interface is uncomplicated and well designed so that it is easy for the users to operate and control the system. Training and guides on how to use it will help, but by having software that is self-explanatory the implementation process will be easier and save resources. Major ERP systems like SAP have integrated solutions in their software to handle information from AIT,[33] and it is important that organizations pick middleware that is compatible with the enterprise software systems that they use.

[32] Michael Maloni and Frank DeWolf, "Understanding Radio Frequency Identification (RFID) and Its Impact on the Supply Chain," (2006): 12.

[33] "SAP Solutions for Auto-ID and Item Serialization," SAP United States, accessed February 23, 2011, http://www.sap.com/solutions/auto-id/brochures/index.epx.

B. APPLICATIONS

The number of applications of RFID technology increases as the technology improves and the cost to implement goes down. This section provides examples of applications of RFID technology and describes how these organizations benefitted from the use of the technology.

Active RFID tags are used for automated toll collections on road systems in Singapore, Norway and in the U.S. Each car is issued a RFID tag that is installed in the car. When the car passes the toll collection point, it automatically registers that the car has passed, and adds the costs for using the toll to the customer's bill. Cars that do not have the tag have to stop at the tollbooth and conduct a manual payment transaction. The main benefit from this implementation is increased transaction speed for the customer; for the toll company it means that less toll booths have to be manned, and the number of booths that take up valuable space can be decreased.[34]

RFID technology has replaced barcodes in some industrial laundries. The RFID tags can be read automatically without line of sight and are more durable than barcodes. This gives the launderer an opportunity to automate their sorting and recording process, and through that decrease their use of manual labor and their error rate. It can also add an anti-theft feature that provides an extra service to the launderers.[35]

Firms that have problems with shrinkage have been successful in using RFID to reduce theft. Breweries mark their beer kegs before shipping them and can monitor kegs throughout the supply chain. If kegs disappear, the breweries have a record of where and when they were last registered. By using this information, breweries can improve their supply chain and reduce costs. This kind of inventory control can also be used by retail operations to reduce theft and prevent inventory loss.[36]

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[34] Geraldo Ferrer, Nicholas Dew and Uday Apte. "When is RFID right for your service?" Int. J. Production Economics 124 (2010): 419.

[35] Ibid., 420.

[36] Ibid.

RFID can be used to control goods that move in a wide network. By marking containers with RFID tags, the movement of the containers can be monitored, and sensors attached can say if the containers have been tampered with during the transportation. This will lower the cycle time for customs that have to control the containers, and provides full time visibility of the items in transit for the shippers, receivers and customers. This visibility might help to decrease the bullwhip effect that increases costs in many supply chains.[37]

RFID can be used to make sure that the right person gets the right service. In hospitals, marking patients with RFID tags provides nurses with information to ensure that the medications provided to patients are the right ones. It can also be used to control the movement of wandering patients with alarm systems that tell when patients leave their approved zones. This reduces the burden on nurses for monitoring and reduces labor costs.

RFID with embedded environmental sensors have been used to monitor food chains. By adding semi-active RFID with temperature sensing sensors, the remaining shelf life of meals ready-to-eat in the U.S. military could be adjusted, which would ensure that food sent to troops is safe to eat. This spoilage control can also be applicable for cool chains that require specific temperature levels to ensure the quality of the products is maintained. This application can reduce spoilage of perishable products, provide information that can be used to improve or change the supply chain, and ensure control of the quality of the goods.[38]

An RFID system can be used in real-time location systems to provide exact information of the location of persons in a fixed location. In mines and tunnel constructions, RFID has been used to track and control the location of workers and equipment in the tunnel. This information is valuable and improves safety in case of an emergency, but also improves asset utilization in the day-to-day operations.[39]

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[37] Geraldo Ferrer, Nicholas Dew and Uday Apte. “When is RFID right for your service?” Int. J. Production Economics 124 (2010): 421.

[38] Ibid., 422.

[39] Ibid., 423.

C. IMPLEMENTATION

Before making a decision on whether to implement RFID in full scale in an organization, a pilot project should be conducted. Through this limited and controllable project, it can be determined if full implementation is advisable, and the pilot will provide valuable knowledge on how the final implementation should be conducted. It can also be used to persuade decision makers to support further progress and investments in the program.

There are two major concerns that have to be considered when conducting a pilot project of a RFID system: the environment where the solution is going to be implemented and which hardware, type of tag, frequency and reader antenna will give the desired results. Since each location can have different characteristics, individual tests must be conducted on the exact location before the system gets set up. The following section describes tests that have to be conducted on-site, and explains how to identify the hardware that is suited for the products that are to be marked.

1. Locations

In a storeroom, there might already be many different electronic devices that are running. These devices create what is called Ambient Electronic Noise (AEN) that will interfere with the RF signals that need to be communicated. The warehouse might also consist of structures of metal that absorb or block the signals that are transmitted. Some electronic devices can be moved or switched off, but the RFID solution will have to be tailored so that it works through some of the AEN in the location.

To examine the presence of AEN in a location, a spectrum analyzer tool that measures the strength of AEN and in which bandwidth the electromagnetic noise is present can be used. This analyzer detects AEN, and by using it over a period of time during all the business operations a map of the AEN in the location can be drawn.

The next step is to test how the reader antenna performs in the actual environment. Supplier-issued antennas with a RF propagation map, as seen in Figure 8, can tell what area and range they are supposed to cover, but this field might change due

to environmental factors in the location it is to be used. By conducting tests, the actual range the antenna will cover in the location can be measured. This is important information when choosing the exact placement of the antenna, and to determine how much power is needed to transmit signals. A passive tag will require one hundred microwatts to be able to reply, so levels below this level will not be able to excite the tags.[40]

2. Hardware Tests

Hardware tests can be done by third-party labs or it is possible to create small independent labs to conduct the tests. This depends on how the organization wants to invest their resources in the project. The location tests will provide information about what ranges to aim for and in what extent the equipment must be able to handle AEN. Hardware tests should be conducted in an environment that is as clean as possible to identify how the RF reacts to the products it is to be linked with.

For the tag tests, the actual product should be used. Objects can be RF-transparent and not interfere with the signal at all; objects can also be reflective and shield or detune the signal, or absorb and remove the energy needed to energize the tag.[41] Some tags are designed to work better on specific materials, and suppliers have a wide range of tag designs available. Within a tag batch, there might be differences in performance, so to obtain a statistically significant answer the tests should be conducted with at least one hundred tags of the same type. The reading range achieved by the tags must be recorded by each tag and calculated on an average for each tag type that is tested. The standard deviation would be as useful a measurement as average reading range for this purpose.[42]

Different criteria might be important for the application that is tested. For conveyer belt applications, read speed will be important, while for other applications a high percent of successful reads at a short range is the most important measure.

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[40] Patrick J. Sweeney II, *RFID for Dummies*, 137.

[41] Ibid., 163.

[42] Ibid., 168.

When the most promising tag type and reader antenna is identified, field tests of the actual solution can be conducted to make the final tuning and ensure that the system works in the environment where it will be implemented. By using lab tests to determine the optimal hardware selection, the onsite tests will take less time and not interfere that much with the ongoing processes in the actual location.

D. BENEFITS WITH RFID

- RFID tags can be read without a direct line of sight to the object itself, and in ranges up to one hundred meters in the extreme. This mean that objects do not have to be unpacked to be read, and that several objects packed on one pallet can be read without splitting up the pallet. This range potential allows for setups where one reader can be used to read a large number of tags and can be placed in a location that suits other operations.
- When the RFID system is properly set up it will work without any direct labor. The system automatically records data from items that pass its zone and generates data that can be used by the ERP system of the organization.
- The microchip in an RFID tag has the capacity to store information that can be used to uniquely identify that object. It can also provide information about the exact history of the product and be linked with a wide range of different sensor systems.
- Passive tags do not contain batteries and can have a long life span. Individual differences depend on design and price, but tags that are able to withstand harsh environmental conditions like high or low temperatures exist.
- Tags can be rewritable so that information on them can be updated, and also the system is not fixed to a certain setup. If needed, the setup and location can be changed or improved to fit with changes in the location where it is used. As it is implemented to one type of objects it is relatively easy to expand the use to cover other categories of materials.
- An RFID system tracks where the items are, provides information on where the items have traveled from, and provides the ability to trigger sensors that either provide information or that automatically respond to changes in the environment the item is in. This provides the organization with information that can be used to improve and monitor their supply chain.

E. CHALLENGES WITH RFID

- An RFID system links different technical components with each other. This implies that they have to be tuned and adjusted so that they can interact. The system can create a huge amount of data which can overload the information system and be hard to interpret for people that make decisions based on these data. Knowledge about the technicalities of RFID can often be limited, and without understanding how the system works it can be hard and expensive to obtain the desired objectives.
- Radio waves used by RFID systems are influenced by both visible objects in the location they are used, like metal structures, and invisible objects created by electronic devices used in the location. This means that the location must be as clean as possible to achieve the best result, and that changes made in the location might influence the quality of the signals gathered by the RFID system.
- Some materials are not well suited for RFID marking. Objects that are made of metal or that contain liquids are in general not suited for RFID tagging.
- Since RFID is affected by outside factors, monitoring is needed to ensure that the system works as intended. If information in the system is not encrypted, it is possible for competitors to obtain information by illegally monitoring the system. Electronically stored data is also vulnerable to data crashes that might erase data stored on the components.

IV. IUID

Item Unique Identification (IUID) is the term that describes optical codes that can be used for unique identification of items. Forty years ago, barcodes revolutionized labeling of goods and items, and today barcodes are a highly utilized technology in inventory management and supply chains. These codes are classified as machine-readable identifiers and require external devices and a line of sight from the code to the device that collects data to interpret the content.[43]

A barcode is a linear code with some inherent restrictions linked to it: it must be read from one direction; it is vulnerable for damage; has a limited storage capacity for information and requires a relatively large space.[44] In 1997, NASA wanted to find a way to individually mark items used in their operations. They needed a marking solution that was compact, secure and that did not require to be on a label. The answer to their request was the development of the 2D matrix code. This code reduces the space requirement, can be read from different directions, has a higher error tolerance and increases the volume of information gathered in the code to over two thousand characters.[45]

The U.S. DoD has adopted the use of 2D matrix technology. In a memorandum from 2004, they require that all items of a certain value are marked with machine readable IUID codes to improve inventory data quality, enable clean audits of a unit's inventory, enable speedy and accurate data capture, and improve visibility of their inventory.[46] Contractors that deliver goods to the DoD that fall within certain criteria are required to mark items according to the DoD's regulations.

An optical 2D matrix code is printed or engraved symbols that represent textual information. A scanner uses light beams to scan the code and the scanner then measures the intensity of the reflected light that comes back from the code. Dark portions of the

[43] James Bensman, *UID Journal Workbook Volume 1*, (UID Journal, 2008), 32.

[44] Norbert Bartneck, Volcker Klaas and Holger Schoenherr, *Optimizing processes with RFID and Auto ID,* 38.

[45] Ibid., 39.

[46] Department of Defense, "Item Unique Identification, 101, The Basics," January 2006: 5.

code reflect less light than lighter parts of the code, and by translating the returned analog light pattern into digitized data, the data stored in the code is obtained.[47] Figure 9 shows the process.

Figure 9. Steps in Reading and Decoding a 2D Matrix Code.

High reading accuracy is the most important criteria for how successful a 2D matrix code is. In many instances, it would be preferable to have a non-read message rather than a faulty reading. The nonread message will be registered and can be investigated, while a faulty read fills the ERP system with false information. Several conditions are important to achieve a high read accuracy: quality of the code; how the code is applied; distance from the reader to the code and the type of material all affect the

[47] Sandip Lahiri, *RFID Sourcebook*, 115.

reading accuracy. In general, a reflection-free and homogeneous background will result in a higher accuracy. An optimal setup of the reader, where it matches the size and resolution, will also improve the probability of a successful read.

While the linear barcode is vulnerable to damages by dirt, moisture or other external factors, the 2D matrix code has a certain redundancy that allows information to be collected despite damages to the code. This feature is called Error Correcting Codes (ECCs). By using algorithms programmed in the design of the code it is possible to recover codes that are more than fifty percent damaged. Damages to the finder pattern field of the code are not possible to recover, so ECCs are of no use during the initial part of the scan.[48] The ECCs increase the probable survival time of the code in all application modes, and makes it more likely that the code can survive throughout the products life cycle. The next section takes a closer look at how IUID technology has developed, how it works, and presents some of the application options that are available for 2D matrix codes.

A. TECHNOLOGY

1. Standards

In a linear barcode, the spacing between each line and the width of the lines themselves are used to provide information.[49] To enable larger amount of data to be stored in the code and to make them more durable for damage, a number of alternative standards have been developed.

Figure 10 shows a standard linear barcode that uses UPC protocol to identify a product. A UPC-A code consists of twelve digits, where the first digit represents the product type, the next five digits correspond to the actual manufacturer of the product, and the last five digits represent the product that is marked. This code is used extensively

[48] James Bensman, UID Journal Workbook Volume 1, 35.

[49] Norbert Bartneck, Volcker Klaas and Holger Schoenherr, Optimizing processes with RFID and Auto ID, 41.

in retail, but it is constrained by limited memory capacity. It is, in general, not possible to identify a specific item using this code, only the product type.

Figure 10. A Linear 1D Barcode Able to Store 128 Characters.[50]

The next step in the development of barcodes is stacked symbologies. These codes are stacked in horizontal layers and create multi-row symbologies. This allows for increased data capacity, improved data density where the code takes less space on the product, and strengthened reading reliability.[51] As seen in the Table 2, the performances of these types of codes are close to the performance offered by 2D matrix codes. Figure 11 shows an example of a stacked symbologies code.

Figure 11. A Stacked, Multi-row Barcode with Storage Capacity up to Thousands of Characters.[52]

The 2D matrix code consists of elements and cells that have similar size and need a specific search pattern preprogrammed in the reader. The fields in the code are binary; they are either dark or light and data is encoded via the relative placement of dark or light

[50] "Linear Barcode," accessed February 24, 2011, http://www.aimglobal.org/technologies/barcode/linear_symbologies.asp.

[51] "Stacked Symbologies," Association for Automatic Identification and Mobility, accessed January 15, 2011, https://www.aimglobal.org/technologies/barcode/2D_symbologies_stacked.asp.

[52] Ibid.

areas in the code.[53] The codes are scalable so the size of the code can be altered to fit the objects without losing data value. The quality of the reader limits how small they can be. As seen in the Figure 12, a black L-shaped border is present. This border serves to quickly detect and decode the information stored in the code. It also allows the code to be read from different directions, as the reader uses this border to adjust to the size and placement of the cells that are read.

Figure 12. There Exists a Wide Range of Different 2D Matrix Code Types; This Figure Shows a Data Matrix ECC 200 Code.[54]

Table 2 shows the number of data that each of these three types of code can contain and the read accuracy that has been found for each of them.

Symbology	**Accuracy**		**Memory Capacity**
	Worst Case	**Best case**	
Data Matrix	1 error in 10.5 million	1 error in 612.9 million	3116 characters
Stacked Barcode	1 error in 10.5 million	1 error in 612.4 million	2525 characters
Linear Barcode	1 error in 394,000	1 error in 800,000	12 characters

Table 2. Barcode Accuracy and Memory Capacity; Note That Memory Capacity can be Improved by Increasing the Size or Detail Level of the Code.[55]

[53] Norbert Bartneck, Volcker Klaas and Holger Schoenherr, *Optimizing processes with RFID and Auto ID*, 41.

[54] "2D Data Matrix Code," accessed February 24, 2011, http://www.aimglobal.org/technologies/barcode/2D_symbologies_matrix.asp.

[55] Sandip Lahiri, *RFID Sourcebook*, 120–127.

2. Application Options

One of the things that distinguish the 2D matrix code from other barcodes is that it can be applied in different ways to the material. Instead of applying the code indirectly to the item through a label, the 2D matrix code can be applied directly to the item. Before deciding which method to pick for applying the code to the item, the type of material and how the items will be used must be examined. Thin and sensitive items are not suited for etching or engraving as it might damage them, and if items are used in harsh environments the code might be damaged as items are used. When testing if the application of a code is successful, it is important to turn the error correcting feature on the scanner off. If not, bad applications can be masked, making it impossible to achieve the optimal marking of the code.[56] Some applications of a 2D matrix code are "write once, ready many" processes, so it is important that the application method suits the item and the environment where it is used.

The quality of the code can be affected by different factors. Good contrasts between the dark and light elements in the code make it easier for the scanner to read them. A code that is not square can cause it to be not readable; this can happen if the surface it is attached to is curved. Modulation can happen after the code has been exposed to different environments; it causes the color patterns in the code to change and makes it hard for the reader to distinguish them. The finder pattern is the most vulnerable part of the code; the system is very sensitive to damages in this part of the code.

For paper, cardboard packaging, wood and some metals, direct marking using an inkjet printer might be best suited. This marking will have no effect on the material properties of the item and is cheap and easy to implement. Codes applied by this method are easily damaged if the items are not protected, and it is best suited for items that are used in controllable environments. To increase readability of the codes, it is important that the printer used is able to produce high contrasts. Applications of a more durable solution using the indirect method exist; in hospitals, an easily attached label that can

[56] James Bensman, UID Journal Workbook Volume 1, 29.

withstand high temperatures has been used with success.[57] In this instance, the hospital used a pressure-sensitive acrylic adhesive to attach the labels to the items. The label resists solvents, oil, grease and salts. One of the major benefits of using an indirectly applied label is that if it gets damaged, it can easily be replaced with a new one.

Engraving changes the surface of the object mechanically by removing materials from items. By using a controlled laser beam, a cavity is made visible and a readable matrix code can be developed. Another way to create a permanent code is by using heating. Some materials change color when heated up, and by controlled heat treatment a code can be made. The heating does not create a cavity in the materials, and is therefore better suited on thin materials that must be kept sterile. The drawbacks of these two application modes are that some materials do not develop color contrasts when heated and the high price for a laser marking system.[58]

Both of these permanent application methods might be affected by changes in the materials over time. Rust that develops on the materials might change the color contrast and the code might become unreadable. The same can happen if the item is heated or oil is applied after it has been marked.

Electro-chemical marking is an application that is well suited to mark metal surfaces.[59] By using a low voltage electrical current a code is etched to the metal surface. This method does not weaken or distort metal parts because it does not affect the surface beyond the depth of the code. This application takes longer time than the other applications, so it is best suited for low volume items.

Pin marking does not damage the materials severely and is cheaper than the laser option. By striking a hard metal pin against the object, a series of interconnected craters that can be read is created. These craters might require more advanced reading devices to achieve a successful read, but low cost and high speed per item marked makes this

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[57] James Bensman, UID Journal Workbook Volume 1, 98.

[58] Norbert Bartneck, Volcker Klaas and Holger Schoenherr, Optimizing processes with RFID and Auto ID, 46.

[59] James Bensman, UID Journal Workbook Volume 1, 83.

application method popular.[60] The low impact on the materials marked makes it ideal for marking thin and sensitive materials. Figure 13 shows a 2D matrix code made with the pin marking method.

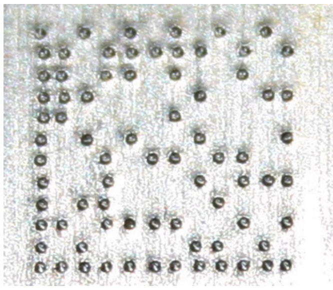

Figure 13. Dot Peen Application of a 2D Matrix Code.[61]

3. Readers

The reader has two main tasks: to illuminate the code and to measure the reflected light returned from the image. A code reading device consists of four basic components:[62]

1. Camera unit with a lens, sensor and camera
2. Lighting
3. Analysis and control unit
4. Casing that connects the components

There are two major groups of readers. One is a stationary installation that is used if the positioning of the codes are the same for all items that are scanned. This system can be applied to register items that are moved on a conveyer belt. Since the distance to the items is fixed and the angle to the tags is the same, a fix-focus lens can be used. A

[60] Norbert Bartneck, Volcker Klaas and Holger Schoenherr, *Optimizing processes with RFID and Auto ID*, 46.

[61] "Dot Peen application of 2D matrix," accessed February 24, 2011, http://www.2Dmarking.co.uk/Products.htm.

[62] Norbert Bartneck, Volcker Klaas and Holger Schoenherr, *Optimizing processes with RFID and Auto ID*, 49.

common application of a stationary reader is used in grocery checkout points in shops all around the world. Figure 14 shows a fixed reader setup used for a conveyer belt application.

Figure 14. Fixed Barcode Scanner in a Conveyer Belt Application.[63]

Directly-marked codes require a more advanced reader than labeled codes. Since the angle and distance from the code to the reader might differ the lens on the reader must be adjustable. These readers are called mobile reading systems and are more sophisticated and flexible than fixed setups. They also require manual labor for operation in comparison with a fixed system that can be automated.

The quality of the code will determine which reader is picked. For 2D matrix codes on paper or labels that have high contrast, a few LEDs will be sufficient for lighting. Directly-marked codes engraved or marked by the pin marking method require lighting devices that are specialized for these purposes. With the use of advanced camera technology like a Charge Coupled Device (CCD), the camera in the reader is linked to advanced analyzing software. CCD readers use a stationary flood of light to reflect the symbol image back to photo sensors in the camera.[64] This image collection and analyzing

[63] "Fixed Conveyer Barcode Scanner," accessed February 24, 2011, http://www.barcodemakersoftware.com/images/view/2426/Conveyor%20Fixed%20Barcode%20Scanner.html.

[64] "Barcode Scanning," Association for Automatic Identification and Mobility, accessed January 15, 2011, https://www.aimglobal.org/technologies/barcode/barcode_scanning.asp.

capability increases the read accuracy of codes that are harder to read. CCD cameras can be used to read both traditional barcodes and 2D codes.[65] Other applications use laser beams to collect information from the code.

A mobile reader can be linked to the ERP system through a standard Ethernet bus connection. The most critical aspect of a mobile reader is its ability to provide sufficient light to gather data from the code. Uniformity in the contrast of the code lowers the need for changing the setup for each item, and by putting the code on places that are easily accessible for the reader one will save time when scanning the code. Figure 15 shows a picture of a mobile reading system.

Figure 15. Handheld 2D Matrix Reader with USB and Bluetooth Connections.[66]

4. Examples of Recent Applications

This section gives some example of how 2D matrix codes are being used in inventory systems, and explains how companies that have implemented them have benefitted from using them.

[65] "Barcode Scanning," Association for Automatic Identification and Mobility, accessed January 15, 2011, https://www.aimglobal.org/technologies/barcode/barcode_scanning.asp.

[66] "Handheld 2D matrix scanner from Hawkeye," accessed February 24, 2011, http://www.microscan.com/en-us/products/Handheld-Barcode-Scanners-and-Imagers/HawkEye-45T-Handheld-Imager-with-Integrated-Display.aspx.

Barrett Firearms Manufacturing supplies rifles to the U.S. DoD. As their products fall under the DoD's requirements for IUID marking, they were forced to implement IUID on their products. Due to low volumes, it was not financially viable to adopt direct marking methods. Instead, they decided to put 2D matrix codes on polyester labels that were indirectly attached to the weapons. The use of indirect labeling gave them the possibility to replace labels if they got damaged when weapons were used or moved. The polyester labels proved to be durable even in the extreme conditions the rifles were used in. Through this implementation, Barrett was able to fulfill the IUID marking requirement from their customer without adding large costs, and they could also use the data in their internal ERP systems.[67]

Postal services have adopted the use of 2D matrix codes in a large scale. By marking each letter individually with a unique 2D matrix code, they can automate their sorting processes, provide more updated information to their customers through tracking information, and achieve cleaner audits due to improved data quality.[68]

Two-dimensional matrix codes are well suited for marking small items. The Electronic Industries Association has picked 2D matrix as a standard for labeling small electronic components. The codes are used to mark integrated circuits and printed circuit boards, and codes as small as two mm are sufficient to provide the information that needs to be stored. The reading processes can be automated and the system provides inventory visibility and tracking of items through the manufacturing process. This application is also used by the automobile industry to mark different car parts.[69]

The pharmaceutical industry has been hit by counterfeit products that both devour their profits and can be a threat to patient safety for patients using false products. Due to this, the industry has adopted 2D matrix codes to enable tracing and validation of its

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[67] "UID Case Study: Barrett Firearms Manufacturing, INC.," Association for Automatic Identification and Mobility, accessed January 19, 2011, http://www.aimglobal.org/members/news/articlefiles/3450-A2B_Tracking_BFMI-cs.pdf.

[68] "Industry Application Table," Association for Automatic Identification and Mobility, accessed January 15, 2011, http://www.aimglobal.org/technologies/barcode/industries_2D.asp.

[69] "Data Matrix 2D Barcode," Jolly, INC., accessed January 18, 2011, http://www.jollytech.com/support/knowledge_center/barcode_symbologies/data_matrix.php.

products. The code is small enough to be fitted on the small product cases often used in the pharmaceutical industry and allows for automated reading processes. IUID has also increased their ability to conduct batch recalls and detect out-of-date products.[70]

B. BENEFITS WITH IUID

- An IUID system only consists of a scanner linked to a computer and the code that is read. This means that it is easy to set up and makes the system user friendly. The system is not affected by changes in the environment it is used in, and works as long it has a clear line of sight from the reader to the code.
- IUID is not affected by the materials in the items they are put on. As long as the code is visible and undamaged, the reader will be able to read it regardless of which material the item consists of. The size of the code is adjustable and can be fitted to the size of the item without losing data accuracy.
- The technology is a direct development from barcodes, which is a matured technology with a proven record. This lowers the risk and uncertainty when implementing it, and suppliers have experience in how to support the implementation.
- Costs for applying IUID are low; a regular printer with sufficient software and a cheap reader is the basic equipment that is needed. More advanced application methods require better tools, but also for them the cost per unit marked is low.
- An IUID system is easy to control and adjust. The system can easily be altered or expanded if needed. This makes the system flexible and enables it to develop to fit new business processes.
- The reading of the codes is accurate and quick with a low error rate. This allows the system to provide valid and trustable data that can be used to increase visibility and information sharing in the supply chain. In a conveyer belt application using a stationary reader, the read speed can be high without losing data accuracy.
- IUID improves inventory accuracy, lowers labor cost connected to inventory management, provides trustable data for audits, and gives the opportunity to track individual items throughout the supply chain and life cycle of products.

[70] "How Datamatrix Barcoding could benefit the pharmaceuticals industry," Manufacturing Digital, accessed January 24, 2011, http://www.manufacturingdigital.com/blogs/editor/how-datamatrix-barcoding-could-benefit-pharmaceuticals-industry.

C. CHALLENGES WITH IUID

- Any optical code system requires line of sight from the reader to the code that is read. This means that the process must be adjusted so that this is possible, or that manual labor has to be provided when scanning is done. Adjustment of the current process leads to investment costs, while the use of direct labor increases labor costs and adds time to the process.
- Codes are vulnerable to damage caused by moisture, injuries or changes in materials. This decreases read accountability, and contingency solutions must be added to register items with damaged codes. Some application methods make the code hard to replace, and in some cases the marking is irreversible. This can increase errors in production and lead to higher costs. Codes that are hard to read require expensive readers and experience in order to be registered properly.
- The 2D matrix codes do not provide more than an advanced serial number with a limited storage capacity. This inherent system limitation means that beside increased memory capacity and increased read accuracy it is not possible to develop the technology to serve further purposes.
- Each code must be read by the reader one code at a time. This increases the time the process takes, and in some cases limits the production or packing processes. Items stored in one pallet must be split up and read individually; this can increase the use of labor and slow down the process.

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V. CASE STUDY: TRACKING WEAPONS AND AMMUNITION FOR THE NORWEGIAN ARMED FORCES

This chapter introduces a case study that examines how AIT can be utilized in the Norwegian Armed Forces (NAF). Currently, there are only a few items marked with barcodes in its inventory management system; most of the high value items are marked with serial numbers either engraved on the items or marked indirectly through labels. Some transports of weapons and ammunition are equipped with manual robbery alert systems, and there are a few video and sensor solutions that monitor major inventories that contain AWA equipment.

The first part of the case study describes the NAF in general, and then focuses on the logistic components in the NAF that are responsible for inventory and material control procedures. The case study covers two applications of AIT: tracking of AWA that are in transit or being transported between two locations and the use of AIT to increase inventory accuracy and make transactions of AWA more cost effective.

To provide valid data about the second application, parts of this research have been conducted in a RFID test laboratory where RFID tags were tested on a small arms replica to determine whether RFID is a feasible and applicable solution for small arms. Previous studies on the use of AIT on small arms are also be described to utilize knowledge from former implementations and research.

A. BACKGROUND FOR THE CASE STUDY

1. The Norwegian Armed Forces

The Norwegian Armed Forces are the Norwegian Authority’s most important tool to enforce the country’s security objectives and secure important national interests. The main objectives for the armed forces are to secure Norwegian sovereignty, contribute to

international peace and stability through participation in international operations, and contribute to the collective defense of other member states of NATO.[71]

The defense budget for the NAF is at about $6 billion annually and in contrast to other nations in Europe the budget has not yet been subject to major cuts. The $6 billion represent 1.7% of the Norwegian GDP.[72] Around one-third of the budget is dedicated to the acquisition of materiel and investments. The government controls military spending through four-year plans. A new four-year plan will be issued in 2012.

Since the Cold War ended, the NAF has been through a severe transformation, both organizational and on the material side. Currently, about 23,000 personnel are employed in the armed forces. This number includes civilian, officers, enlisted and conscripted forces. The Commander-in-Chief is H.M King Harald V, while the strategic leadership is conducted by the Norwegian Ministry of Defense led by the Defense Minister appointed by the government. Day-to-day operations are led by the Chief of Defense, a four-star General, and the Defense Staff.

Figure 16 shows the four main branches of the NAF. The Norwegian Defense Logistic Organization (NDLO) is outside the branches and all branches are supported from the logistics organization. In military terminology, this is called a purple logistics organization.

[71] "Norwegian Defence Facts and Figures 2010," Norwegian Armed Forces, accessed January 28, 2011, http://www.mil.no/multimedia/archive/00141/Fakta2010_engelsk_141161a.pdf.

[72] "Financial and Economic Rata Relating to NATO Defence," NATO, accessed January 17, 2011, http://www.nato.int/nato_static/assets/pdf/pdf_2010_06/20100610_PR_CP_2010_078.pdf.

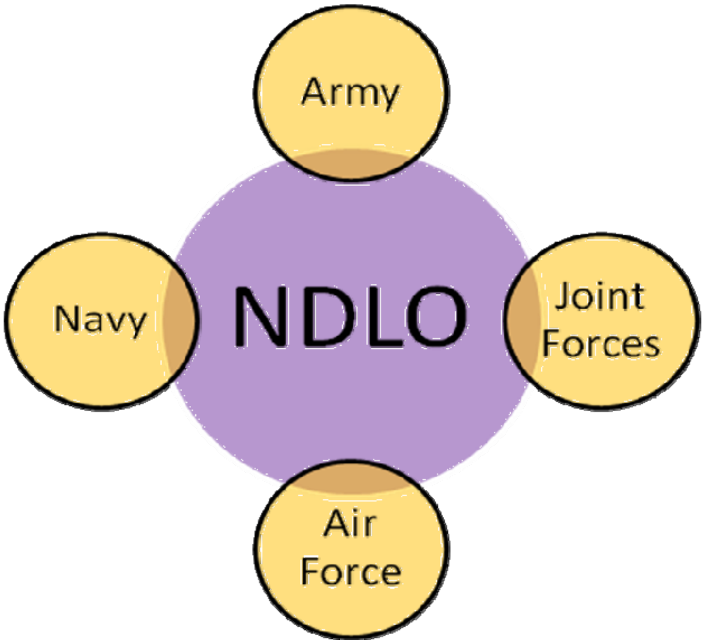

Figure 16. NDLO is Responsible for Logistics in all Branches.

2. Norwegian Defense Logistic Organization

Before 2002, several separate units outside and inside the four branches were responsible for their own logistics support. To become more cost effective and to achieve economy of scale benefits, all logistic support units were consolidated into one unit in 2002. The unit, called the Norwegian Defense Logistics Organization (NDLO), has the mission of delivering logistics according to all military needs. This includes procurement, investment, support, and supply and maintenance of all weapon systems and military materials. The NDLO is also responsible for base services and follows the armed forces when needed on deployments in international operations.

Due to the ongoing transformation process in the NAF, the tasks and organization of the NDLO are due to be adjusted. Some responsibilities will be removed from the purple unit and are again to be linked directly to the different branches. Despite this, the NDLO will remain the core logistics organization in the NAF. It will be responsible for inventories and logistics procedures and lead major investment projects.

3. Attractive Weapons and Ammunition

In 2005, the Defense Staff gave the task to the NDLO to establish a group to assess the current policy and procedures regarding the storage and transport of weapons, ammunition and explosives. The NAF is excluded from the regulations that control the storage of these kinds of materials in Norway. This means that the NAF is responsible for establishing its own regulations to maintain adequate safety and security on these matters. Based on the conclusions from the group, a program with a number of initiatives was developed, with milestones for implementation and a budget. The program was organized as a portfolio of different investment projects, and the responsibilities for the different projects were allocated to different departments in the NDLO and the Norwegian Defense Estate Agency. A colonel in the NDLO was given the overall responsibility for the program.

The program was named attractive weapons and ammunition, and it aims to control items that might have a negative impact on public safety if they are lost or items that are easily sold on the illegal market. Weapons and ammunition in this context are defined as follows:

Weapons: Portable weapons owned by the NAF that can be operated independently of a larger platform. These weapons are divided into two categories based on their characteristics, as listed in Table 3.

Category	Type	Characteristics
Hand Weapons	Hand Guns	*Easily traded, easy to hide*
	Machine Pistols	*Light weight , easy to operate and high firepower*
	Assault Rifles	*Light weight , easy to operate and high firepower*
	Sniper Rifles	*Range and precision*
Special Weapons	Sniper Rifles, 50 Cal	*Range , precision and high firepower*
	Heavy Machine Gun	*High firepower*
	Recoilless Rifle, 84mm	*Threat to armored vehicles and fortified objects*
	Grenade Launchers	*Firepower*

Table 3. Weapon Types and Characteristics.[73]

Ammunition: The ammunition items included in the program are ammunition that contains explosives. Ammunition that can be obtained easily on the private market is not included and ammunition that does not represent any threat to the public if it is lost is also excluded.

The programs vision is:

- The NAF must secure the storage and transport of weapons and ammunition so that these are not available for people outside the NAF.
- There is zero tolerance for the loss or misuse of attractive weapons and ammunition.
- If attractive weapons and ammunition are lost during transport, the system must include measures that make tracking of the missing items possible.

The program also aims to achieve a cost reduction of $6 million per year, and it emphasizes that operational units must be hampered as little as possible because of AWA regulations. Full inventory accuracy of AWAs, combined with a status of the condition the items are in, must also be established.

[73] Translated from: Morten Jacobsen, "Retningslinjer for sikring av attraktive vaapen og ammunisjonsartikler (AVA) i Forsvaret," May 21, 2008: 9.

The two projects this thesis covers are marking AWAs and securing and tracking AWA in transport. Physical security improvements of storage facilities and consolidation of inventories are examples of other projects that are a part of the attractive weapons and ammunition program but that are not covered in this thesis.

B. THE USE OF ACTIVE RFID TO MONITOR THE TRANSPORT OF HIGH VALUE ASSETS

This part of the thesis describes the use of RFID to monitor the transport of high value assets. Requirements and the current process are explained first, and then a recommendation of how RFID can improve the process is presented. For this application only a RFID application is described; this is because the requirements of the project description in the AWA documents can only be accomplished with an RFID system.

1. Project Description

The project that covers the transportation of AWA is described as follows:

> Secure and recover AWA in transport: The project must acquire solutions that automatically can monitor transports of AWA using a mobile alert system and eventually other sensor systems connected to the vehicles or cargo. The system must enable recovery of lost transports using GPS, GSM or HF technology or a combination of these.[74]

The following section describes the process when AWA is transported: The process is initiated through a written order issued from the NDLO. The order contains information about who is responsible for the transport; what the transport contains; from where the transport departs and what the destination is; which mode of transport is to be used and who is authorized to receive the items at the destination. Figure 17 shows a flowchart of the process that is currently used.

[74] Translated from: Terje Noren, "Prosjektforslag program AVA," December 4, 2008.

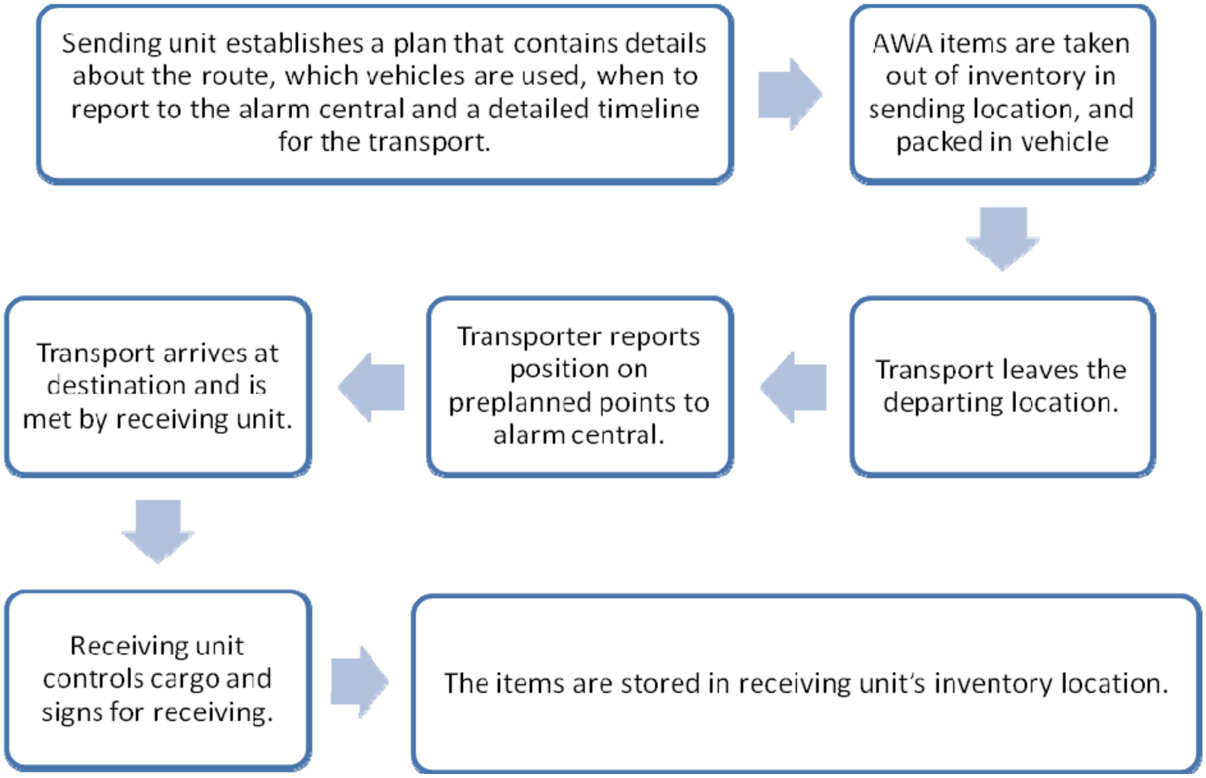

Figure 17. Flowchart of the Transport of an AWA Process.

2. System Requirements

Based on the project description, the system must fulfill the following requirements:

- Real-time tracking of items
- Enable embedding of sensor systems
- Secure the transport
- Compatible with the ERP system

A hybrid RFID system like the one offered by Savi Technology (see Chapter III) can accomplish these objectives. By using a hybrid solution, there is less need to build up a wide-stretching network of interrogators, but the use of alternative communication modes like satellite systems will increase communication costs. There are hybrid tags on

the market that use GSM or GPRS telecommunication technologies to communicate,[75] and the costs connected to this communication are lower than with satellite communication.

The fact that active and hybrid tags transmit information to its surroundings might increase the risk for these transports. Even though the target for the NDLO is to increase visibility of the supply chain, it is important that the information is not publicly available. Criminals with scanning equipment might use information extracted from tags to plan and execute actions against the transports. The tags must therefore include encryption that make them secure to use. Another threat to active tags is equipment that can block or interrupt the transmission from the tags. This would enable criminals to disable the tags and disappear with the content without any ability to track them. A perfect solution is not achievable, but the system must be rugged enough to recognize blocking or tampering attempts.

3. Recommended Solution

This section describes the technical requirements for the RFID system that covers transports of AWA for the NAF.

a. For Tags

Tags need a read range greater than five meters to limit the number of interrogators needed. The tag must be programmable by the users as the content of the transports vary frequently. The tag must also be a hybrid so that it can communicate with the frame system through different modes of communication and contain the following options:

- A GSM application so that the system can use a GSM network to report its position after it has left the interrogation zones.
- An alarm function that automatically alerts alarm central if the tag is tampered with or becomes dysfunctional.

[75] Bacheldor, B. “Hybrid Tag Includes Active RFID, GPS, Satellite and Sensors,” (RFID Journal, 24 February, 2009): 2.

- A GPS sensor so that the tag can report its position with high accuracy.
- Encryption systems so that the system cannot be monitored by outsiders.
- Be programmable so that it can report position at preset time intervals, and be manually programmed for each transport.
- The tag must be tested against ordnance that is sensible to radio waves to ensure that they do not increase the risk of an unwanted detonation.

b. For Interrogators

RFID readers must be installed on locations that ship or receive AWA. The physical attributes of the location determines the setup of each site, and individual tests must be conducted on each location to ensure that the reading range of the antenna is adequate. Communication outside of the location must be done through the GSM network.

c. For Software

Each location must have the capability to individually program the tags according to the plan for each transport. Middleware must also be linked directly to the ERP system so that movements in and out of the locations are automatically reported in the central ERP system.

4. System Application

The process is initiated in the same way as without the RFID system with a written order from the NDLO. Figure 18 shows a flowchart of the process using RFID technology. Dotted boxes show how processes are altered or added due to the RFID implementation.

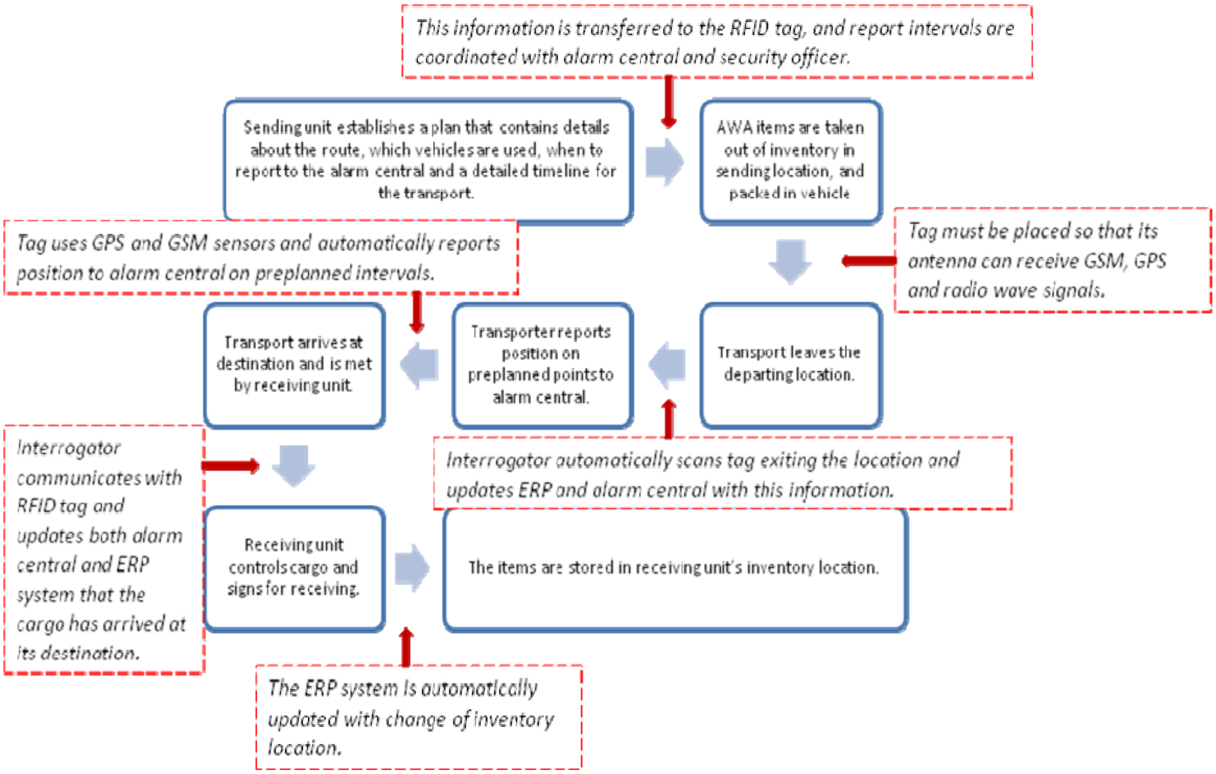

Figure 18. Flowchart of an AWA Transport System with RFID. Dotted Boxes Show RFID Interaction.

5. Summary of Recommendations for the Transport of AWA

Through the RFID implementation, the NAF will be able to conduct real-time tracking of AWA items in transport. The use of RFID automatically provides information to the ERP system, and through a mix of RFID, GSM and GPS sensors the alarm central will have updated info about the exact location of the transport. By choosing a hybrid system, the number of interrogators that have to be installed and monitored will be minimized, thereby lowering investment and variable costs. The encryption system that is included prohibits outsiders from gaining access to information transmitted through the system. The special requirements for the tags used in this operation imply that they will have to be tailored to this application; it is therefore difficult to estimate costs per tag, but a range of \$50–\$100 per tag is a realistic estimate, and each interrogator would be in the range of \$500–\$1500.

This system can also be used by other units in the NAF. High value or high priority items that travel long distances or take a long time to their reach their destination would be well suited to use this system. Supplies to operational units in international operations fit this description. These transports often have items that are high priority, travel through several transportation modes, and pass through a fixed set of chokepoints during the transportation. By using active RFID tags and either building a network of interrogators or linking through a hybrid system using GSM or satellite communication, the operational units will receive updated info of where their supplies are in the supply chain. This gives them a better ability to conduct and plan their operations.

C. EARLIER APPLICATIONS OF AIT ON SMALL ARMS

This part of the thesis describes specific studies that have been conducted on the use of AIT in small arms inventories. The first is a case study of the implementation of RFID in armories in the British Police Force in 2006, and the second is an assessment of the implementation of IUID for the small arms inventory of the USMC written in 2008.

1. RFID in British Police Force Small Arms

The study, called "RFID Weapons and Armoury Management Systems was published in 2006. The study was conducted as a result of a review after complaints of police shootings in England and Wales. The purpose of the study was to determine whether an RFID system could be used to control issuing of weapons, give info on the location of weapons, provide an auditable record of the weapons and ammunition, and generate real-time reports that could be used by management.[76]

Weapons for police officers are stored centrally and only taken out of the armory when they are needed for training or when an actual incident occurs. Each police officer would be issued an RFID-tagged personal identity card and use this card to identify himself or herself when a weapon was taken out of the inventory. A RFID tag was

[76] Graham Dean, "RFID Weapons and Armoury Management System, Applying the technology to an armoury application and description of a Case Study," Home Office Scientific Development Branch 25/06, (2006), 5.

attached to each weapon and by reading each weapon with a handheld reader, the database was updated automatically with information of each transaction. A software system was developed to control the transactions, and reports could be generated based on the transactions. The system was also linked to a short message service that could send a notification, if an unauthorized officer tried to enter an armory, or if weapons were not returned after use.

The main benefits of the system were that it created a clear auditable trail of each transaction, eliminated manual errors, increased transaction efficiency, and gave management an overview of the use of weapons. The study identified the limited reading range of RFID tags on metal as a challenge, with reading ranges at only a few millimeters experienced in some applications.

The final conclusion of the project was that RFID technology is feasible for weapons and armories; however, off-the-shelf solutions would most likely not be suitable so extensive testing was highly recommended.[77] It also recognized that retrospective fitting of tags was not ideal, and presence of gun oil and metal surface made gluing tags to the items difficult. The project included the development of a standalone software system, but in a real implementation a network with the applied ERP system was stated as essential for success of the system.

This case study did not present any actual data on the readability of the tags when attached to weapons. This could be a major flaw of the system that determines whether it is applicable or not. The author of the study confirms in an email that he did not perform specific testing to determine the reading range of the RFID system. The conclusion was based on test applications by the users that cannot be compared or repeated. One of the important lessons he learned was that not two locations were similar, so that the application had to be tailored to each location. The author confirmed that the RFID application had actually been implemented in several police forces in the United Kingdom after this study was conducted.[78]

[77] Graham Dean, "RFID Weapons and Armoury Management System," 60.

[78] Graham Dean, e-mail message to author, February 14, 2011.

Figure 19. An RFID Tag on the G36 Assault Rifle in the U.K. Police Force.[79]

2. IUID on USMC Small Arms

The MBA Professional Report called Feasibility of RFID and IUID in the Marine Corps Small Arms Weapons Tracking System and written at the Naval Postgraduate School examines the current state of the USMC's armory process, the feasibility of implementing RFID or IUID technology in small arms inventories, examines current research on RFID and IUID with small arms, and recommends implementation of these technologies in the USMC armory system.[80]

Several site visits to military installations that had already implemented IUID technology on small arms were conducted, and the test reports from internal DoD study groups on the use of IUID applications are included. For IUID, environmental test data published by Boyle in 2006 was used.[81] According to these tests, IUID codes are vulnerable to environmental impacts by salt fog, sand and dust. Deep laser engraving,

79 Graham Dean, "RFID Weapons and Armoury Management System 20.

80 Rico R Harris, Dale F. Locklar and Luke R. Wright, "Feasibility of Radio Frequency Identification (RFID) and Item Unique Identification (IUID) in the Marine Corps Small Arms Weapons Tracking System" (MBA Professional Report, Naval Postgraduate School, 2008), V.

81 William Boyle and Michael Friedman. "Small Arms UID," DTIC Online Information for the defense community, May 17, 2006.

indirect marking through tape, and laser-etched IUID codes were tested on thirty weapons. The codes marked indirectly on adhesive labels covered with a clear coat showed the best results. Figure 20 shows a laser-etched code after environmental testing was conducted.

The report compares IUID and RFID and grades them according to their performance in different applications and locations in the supply chain. RFID achieves an average score of 3.375 and IUID 2.8125 in this ranking.[82] The report recognized that the IUID application technology currently used is not adequate for the needs of the USMC, and recommended that a combination of RFID and IUID technologies would be better than using them separately.

The report recognizes that the data sources for the current use of IUID are limited and does not include any test data on the use of RFID tags on small arms. It is difficult to draw any conclusion on the assessment of the current implementation of IUID based on data presented by this report. Based on this study, it seems like the use of IUID in the USMC lacks necessary support and infrastructure to be able to succeed. High tempo in USMC operations and the fact that it has just recently been introduced might be reasonable explanations for these shortcomings.

[82] Rico R Harris, Dale F. Locklar and Luke R. Wright, “Feasibility of Radio Frequency Identification 68.

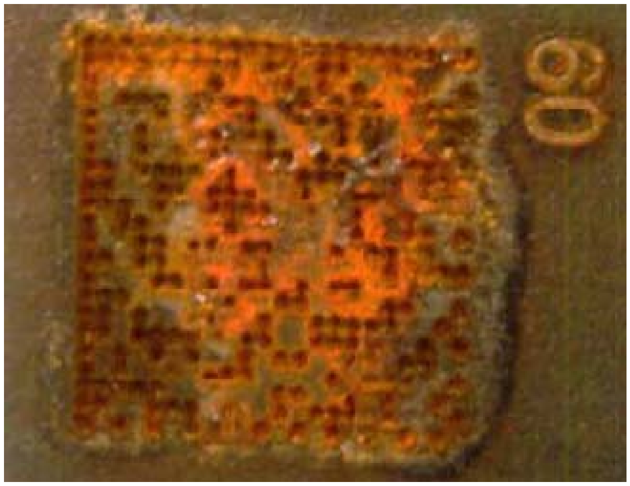

Figure 20. Laser-engraved 2D Matrix Code after Environmental Testing in Salt Fog Tests Conducted by the U.S. DoD in 2004–2005.[83]

D. AIT OPTIONS FOR SMALL ARMS INVENTORY

This part of the thesis describes the NAF's objectives for implementing AIT in its small arms inventory. The current solution for small arms inventories and the processes that the implementation will affect are also covered. Then three different possible implementations of AIT are discussed, and based on this a solution is recommended.

1. Project Description

The project that covers the marking of small arms is described as follows:

> Establish a system that allows for increased control of the location of AWA. The system must allow for item unique id of all weapons, and for some ammunition items. A system for reading the codes and integration with NAF's ERP run on a SAP system must be a part of the system. The idea is to make the system electronic, for example with RFID technology.[84]

[83] Rico R Harris, Dale F. Locklar and Luke R. Wright, "Feasibility of Radio Frequency Identification," 48.

[84] Translated from: FLO Systemstyring, "Programdokument 2 for Forbedret forvaltning av attraktive vaapen og ammunisjon i Forsvaret AVA June 1, 2008.

There are currently about one hundred locations in Norway where AWA is stored, and in these locations there are over 1,200 unique inventories that contain AWA. The consolidation of inventories might lead to a decrease in the number of inventories in the future. The total number of weapons that are to be marked is around 150, 000, and there are also ammunition items that might require unique identification. In total, the number of unique items is 175,000.[85] A typical location in the Air Force has a central inventory with about 350 weapons and 600 weapons allocated among six inventories managed by the units that use the weapons. Workshops, army bases and main depots will have larger amounts of weapons and a different turnover of weapons.

Figure 21 shows a flowchart that describes the current process of handing out weapons from the NDLO central inventory in a camp to a user that belongs to an operational unit.

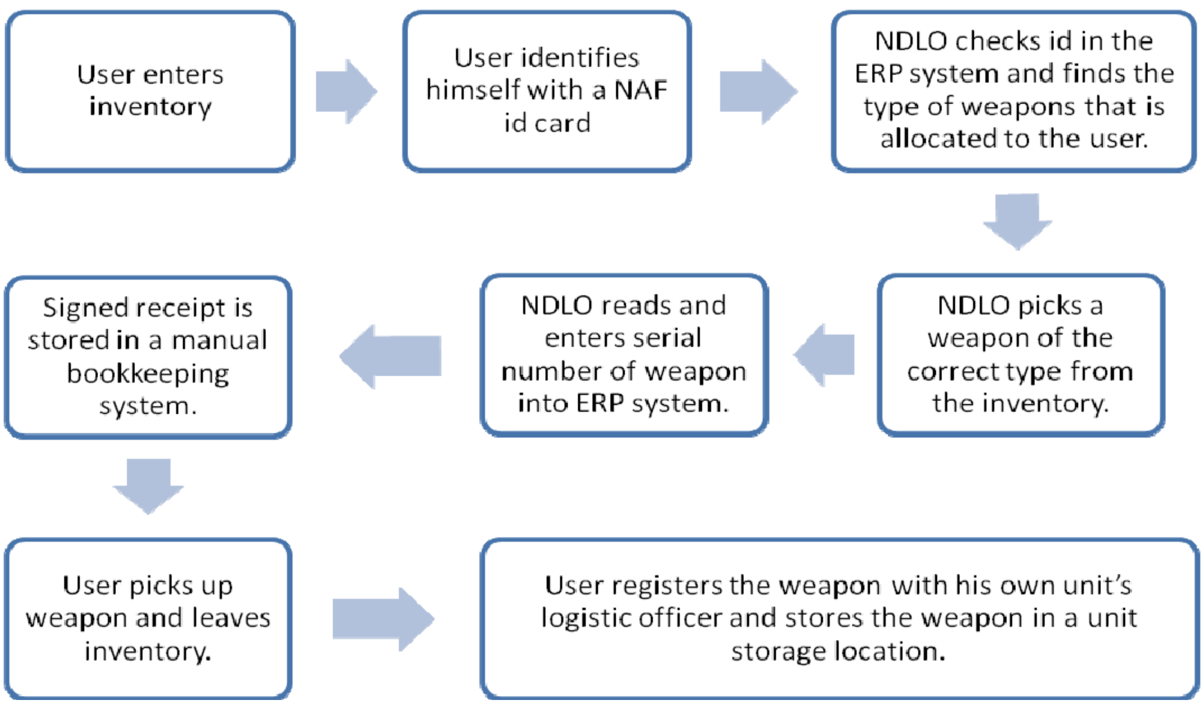

Figure 21. Flowchart of the Delivering Out Weapon Process.

85 Terje Noren, e-mail message to author, January 4, 2011.

Every month, all inventories containing AWA must be accounted for and controlled. The flowchart in Figure 22 describes the current process.

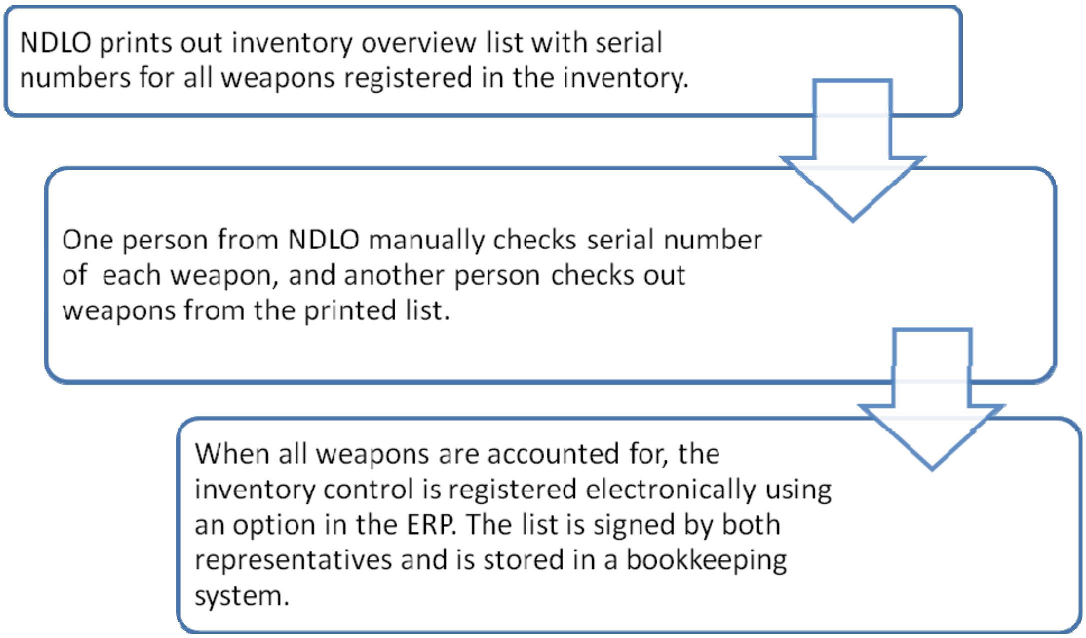

Figure 22. A Flowchart of the Monthly Inventory Control Process.

Every year, all personnel that have a weapon signed out must bring their weapon to the central inventory in their respective location to re-sign it. The flowchart in Figure 23 describes the current process.

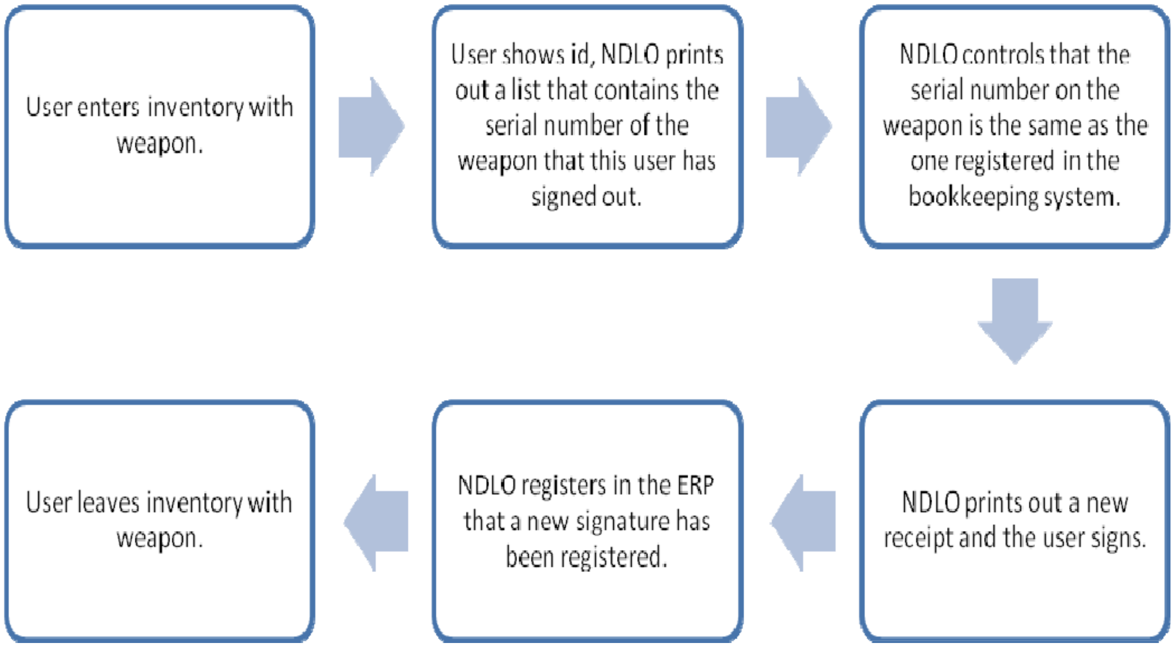

Figure 23. Flowchart of Annual Re-signing of Weapons.

In the following section, four different options are presented: the first one is the current solution; the second option uses only RFID; then a solution that uses only IUID and finally an option that will use a tandem of RFID and IUID for inventory management.

2. Current Solution

In the current solution, no AIT is used. Inventory control is done by manually controlling each item's serial number and checking against a printed list from the ERP system. The serial number is engraved on the weapon, or in the case of ammunition, printed on the box or item. The physical setup is different at every location. When transactions are performed, the operator visually checks the serial number and types it into the ERP system to register it electronically to the person that receives the weapon. Even without investing in AIT, infrastructural changes would increase transparency in inventories and make inventory control processes more efficient. Figures 24 and 25 illustrate the current solution.

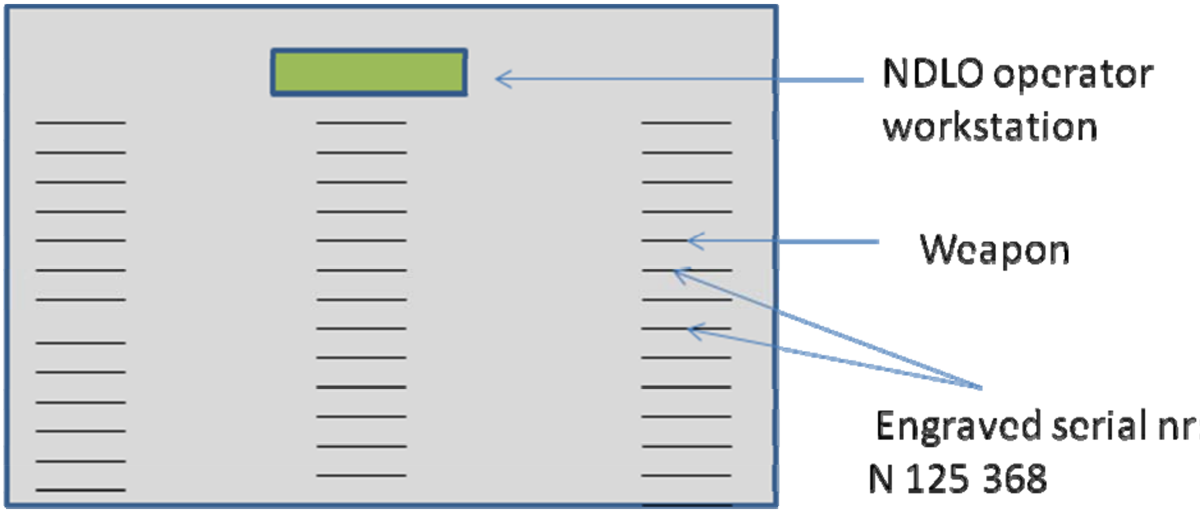

Figure 24. Draft of the Current Solution Where Weapons are Controlled by Serial Numbers.

Figure 25. The Current Inventory Solution from one of the Central Locations.

3. RFID Solution

A RFID solution requires a system of components installed and tuned to the desired function. Each item is tagged with a RFID tag tailored to work in proximity to metallic surfaces. Readers and antennas must be installed and tested at each location where the system is to be operational. In addition to the fixed antennas, handheld readers

must be available to give flexibility to the operators of the system. Also, a table antenna close to the transaction area should be installed to enable tracking of weapons that are moved in or out of inventory. The system is linked directly with the ERP system, so that transactions are registered automatically. Infrastructural improvements and changes will be necessary to get the system operational; tailored racks, removal of metal obstacles and the adjustment of other electrical components that interfere with the radio waves are some of the necessary improvements.

When items are moved out of inventory, the operator picks up the weapon and puts it on the RFID-enabled table or uses a handheld reader. The information stored on the tags automatically pops up in the ERP system and the transaction gets registered in the ERP system. Inventory control is done automatically in locations where the antenna has the reading range to accomplish this, and in more demanding locations it is done by using a handheld reader on each item. A physical count of weapons must be conducted to control the results, as the RFID system only controls for tags, not for the actual weapons. Figures 26 and 27 illustrate the RFID solution.

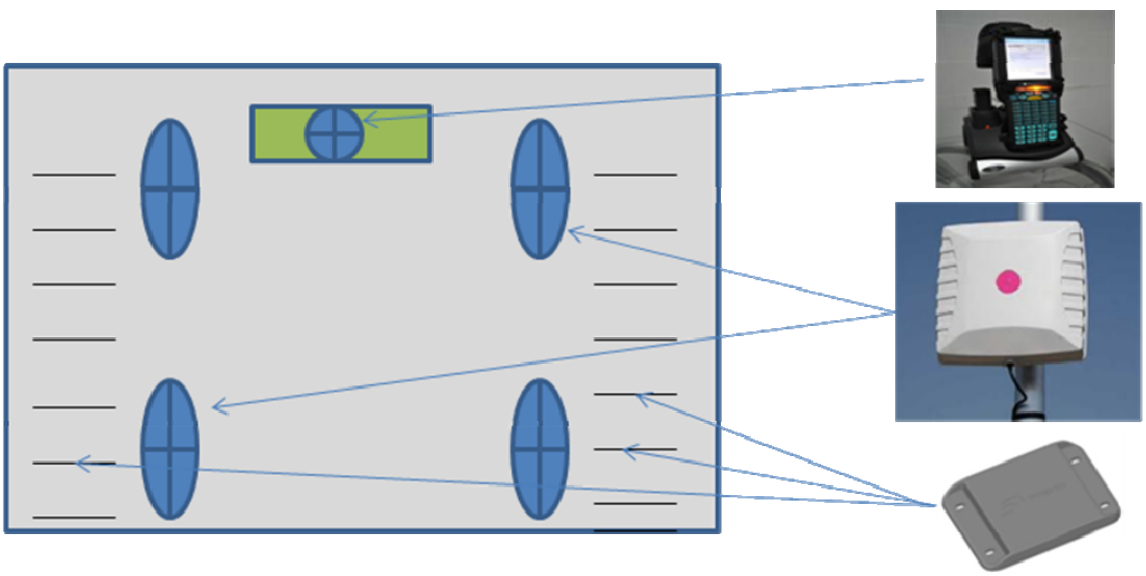

Figure 26. Draft of a RFID Solution Where Weapons are Tagged at the Item Level. Interrogators are Spread in the Room to Achieve Contact with Tags, and the Operator has a Reader at his Position.

Figure 27. RFID Small Arms Inventory System from ODIN Technology.[86]

4. IUID Solution

Two-dimensional matrix codes are indirectly attached to the weapons with codes printed on adhesive tape. Each location is issued handheld readers tailored to read this type of code. The handheld reader is automatically linked with the ERP system. When transactions are conducted, the operator brings the weapon to his or her workstation, scans the weapon with a handheld reader making the data pop up in the ERP system, and the transaction is registered automatically.

Inventory control is conducted by using the handheld reader and individually scanning the code of each weapon in the inventory. When designing the physical inventory setup, the line of sight requirement from reader to code must be taken into account. The weapon racks must be tailored so that the code is easily readable for the operator without having to move the weapon. In cases where the code is damaged and

[86] "Automated Weapons Tracking – Easy Arms TM," Odin Technologies, document sent to author February 10, 2011.

becomes unreadable, the operator can print out a new code based on the weapon's serial number and replace the damaged IUID. This is only possible if an indirect application mode is selected. Figures 28 and 29 illustrate the IUID solution.

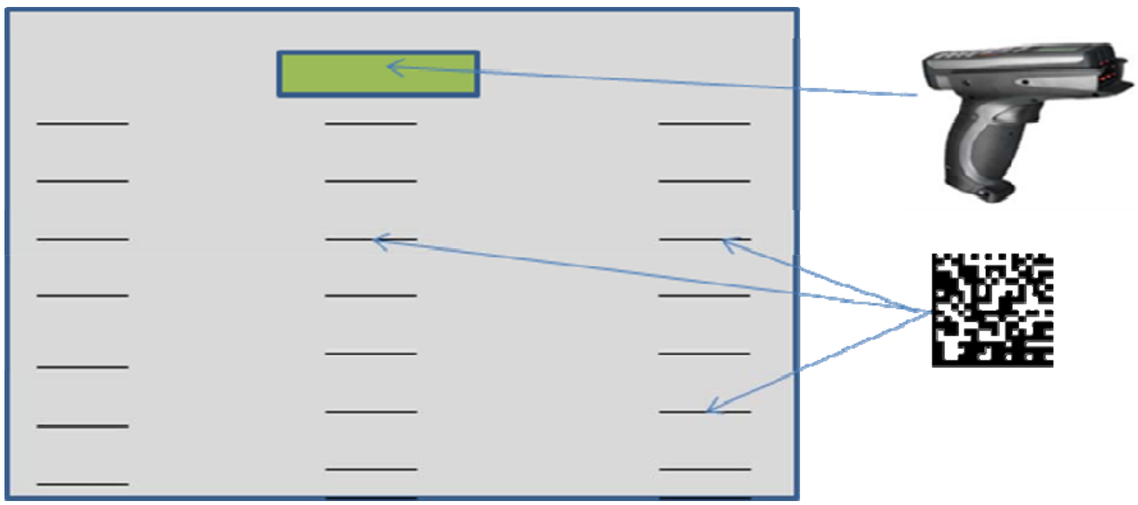

Figure 28. Draft of an IUID Solution. Notice the Increased Spacing Between Each Item to Enable Easy Scanning.

Figure 29. Application of 2D Matrix Code on a USMC M240 Rifle.[87]

[87] Rico R Harris, Dale F. Locklar and Luke R. Wright, "Feasibility of Radio Frequency Identification," 57.

5. Tandem Solution

In this solution, an RFID system is installed only in the one hundred central inventories. Each item is marked with an IUID as in the IUID solution. In central locations, weapons are stored in sealable plastic boxes instead of in racks. The seals must be easily controllable so that the operator can distinguish which boxes are covered by the RFID system and which are not. The items stored in the boxes are registered on a passive RFID tag and the tag is attached to the box. This requires the use of a RW tag and software that makes tag programming easy. As the RFID tags are not attached directly to metal, it will be easier to accomplish a good read rate, and less investment is needed to tailor each location.

Transactions are conducted in the same way as in the IUID solution using the 2D matrix code. Whenever a box is opened, the RFID tag must be updated by reading each item's IUID code and register them as content in that box through the RFID system. Boxes that are not sealed must be moved to another location and the content is controlled by the IUIDs. Inventory control is conducted by using the RFID system on the boxes that are sealed, and items that are not in a sealed box must be controlled individually as in the IUID solution. A visual control of the seals must be done to ensure that no items have been removed or added to the box. Both the RFID and IUID systems must be linked up with the ERP system. Figures 30 and 31 illustrate the tandem solution.

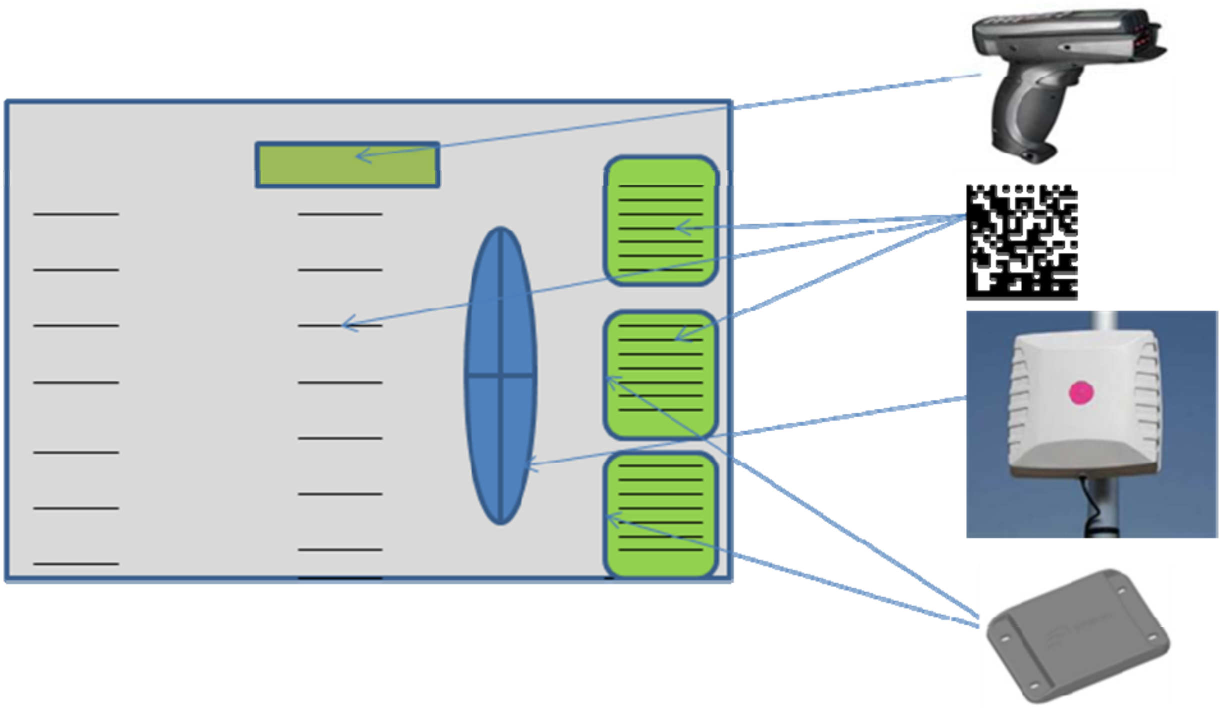

Figure 30. Draft of a Tandem solution. A Portion of the Items are Stored in RFID-tagged Boxes.

Figure 31. Pelican Boxes are Currently Used to Store MP7 Guns. This Kind of Box Would be Well Suited for the Tandem Solution.

E. EVALUATION OF THE OPTIONS

This section uses criteria that are important in the NAF AWA inventory system and describes how each of the four scenarios described in the preceding section complies with them. The criteria that are examined are accuracy, complexity, durability and costs. These criteria are picked because they are vital in the success of the implementation and they are the drivers of both investment and life cycle costs for the different options.

1. Accuracy

Inventory accuracy is affected by errors made when recording the identity of items. An item that is inaccurately recorded can be considered a failure and will decrease the reliability of inventory data in the ERP system. To measure the failure rate, a mean time between failures (MTBF) is calculated. By multiplying this number with the number of transactions, the actual impact on inventory accuracy can be calculated.

In the current solution, using manual reading and typing serial numbers into the ERP system causes high variability in inventory accuracy. Error rates will depend on the concentration level of the operator who reads the numbers. Parallel systems where two people control the numbers will increase reliability, but also increases labor costs significantly. Audits in 2011 revealed that over one thousand items were missing from inventories in the NAF; this is not a vote of confidence for the accuracy of the current manual solution.

An RFID system that is tested and able to achieve contact with all tags in the inventory will give a high read accuracy. ODIN Technology advertises a read rate of 99.5% on their small arms inventory system,[88] but errors in this system can occur if the radio waves are interrupted by outside factors like AEN, or if mistakes are done while programming the tags. Despite the high read rate, the RFID system only registers the presence of the tags, not the actual items. There is therefore a possibility of registering

[88] "Automated Weapons Tracking – Easy Arms TM," Odin Technologies, document sent to author February 10, 2011.

weapons as present in inventory even though only their tags are there. The RFID system does not require any manual labor to conduct inventory control and enables accurate real-time updates of the inventory in the ERP system.

Two-dimensional matrix codes can achieve very high read accuracy rates. In an experiment conducted by Ohio University, the results ranged from one error in 10.5 million in the worst case scenario to one error in 612.9 million in the best case scenario.[89] Damage to the code due to environmental impact will lower the expected read accuracy for this application. The IUID system will give the operator instant feedback if the code is not read properly. This enables the operator to identify faulty reads at once, and lowers the chance of importing corrupt data into the ERP system. By using an indirect application, the code can easily be replaced with a new one. This backup option gives this system a very high read accuracy and a low error rate.

In the tandem solution, the accuracy benefits are similar to the IUID solution. By using RFID attached to plastic boxes, the read accuracy from the RFID part of this system will be higher and easier to accomplish than in the RFID solution where tags are attached directly to metal. By grouping the benefits from both systems, the tandem solution has great potential to achieve very high inventory accuracy.

2. Complexity

The number of different components that must communicate, how advanced the technology is, and whether the system is sensitive to environmental factors are all important measures to determine the complexity of the system.

The current system is not very advanced as transactions and inventory controls are conducted by manual labor performing easy repetitive operations. No electronics are used in this system. This presents a low level of complexity.

Using RFID on metallic surfaces requires tuning of different components in the RFID system perfectly to each other to achieve good results. The physical location must be tailored to become as radio wave friendly as possible. Errors in the system must be

[89] Sandip Lahiri, *RFID Sourcebook*, 127.

controlled by personnel who have very good understanding of the underlying technology. This makes the RFID system a very complex and technology-driven solution.

When the 2D matrix code has been attached to the items and a suitable reader is used to scan the codes, there is not much complexity to this system. Linking the reader electronically to the ERP system will require some tuning, but none that require more skills than setting up a wireless network. Since infrastructure and the physical setup of each location will have no affect on reading the codes, one solution will fit each location. This means that there is no need to perform individual tests on each location.

In the tandem solution, the complexity for the IUID part is the same as for the IUID solution. Since the RFID tags in the tandem solution are not attached directly to the metal surface of the objects, the setup of the RFID system will be easier and require less adjustment to achieve good read rates. This gives this system a moderate level of complexity.

3. Durability

The items that are marked will be in operational use; this means there will be diverse environmental impact to the AIT that is applied to the items. High temperatures, moisture and weapon oil are some of the conditions the items face on a regular basis. Durability in this context is defined as how likely the AIT is to be affected by this impact and how easy it is to repair AIT that has been damaged.

The current solution uses engraved serial numbers that can withstand environmental impact and do not lose readability of the serial number needed to control the item. This gives the current system a high level of durability. The engraved serial number will also be used as a backup and master data system in the other solutions.

Attaching a RFID tag on the surface of a weapon will increase the likelihood of damaging or losing the tag. As long as the weapons are stored in a central location, the tags will be in a stable environment, but as soon as they are used, damaged or lost tags are probable. The extent of the loss is determined by how the tag is attached and robustness of the tag itself. By placing the tag embedded inside a storage compartment in

the weapon, the tags will be protected from some of the environmental impact. As these storage compartments are detachable and are not part of the central components of the weapon, the accuracy of the system will be affected negatively through this placement of tags.

The ability to read a 2D matrix code is affected by the quality of the code and the sensitivity of the reader. Even though the code is readable just after it has been applied, it will be affected by environmental impact after the item has been in use. Scratching, weapon oil or temperature changes might damage the code and make it unreadable. The error correction ability of the system that allows parts of the code to be damaged without losing accuracy gives the system some redundancy towards damages. If a pin marking application is used, replacing the code will be a demanding task, while the indirect application method allows for quick replacement. Also, the choice of where to place the code on the weapon will affect the amount of damage likely to affect the code.

In the tandem solution, the IUID part has the same durability characteristics as the IUID solution. The RFID part of the system is only used in controlled environments inside the central locations and therefore does not have the same durability concerns as when RFID tags are directly attached to the items.

4. Costs

There are two major costs to consider. Investment costs cover the acquisition of technology and infrastructure improvements needed to get the system operational. The other main cost is the labor cost connected to the day-to-day operation of the system.

Infrastructural improvements to improve transparency and visibility in the current solution will require investment cost in storage equipment and some structure changes in the inventory locations. The current solution is labor intensive with manual labor involved in all transactions and inventory controls. If double-checking measures are introduced to increase the reliability of the system, this will further increase the labor cost connected to the current solution.

In the RFID solution, major investments in antennas and readers are required to accomplish acceptable read rates to manage signal exchange with RFID tags attached to metallic surfaces. In addition, infrastructural changes and individual testing of each location adds to the investment cost in this solution. An RFID antenna might cost up to $500 per piece and several will be needed at each location to achieve good results. The price of the tags themselves has dropped considerably over the last several years, but the specific requirements for the RFID tags in this application mean that the cheapest off-the-shelf solution will not be applicable. Also, the costs to replace lost or damaged tags must be considered. The labor costs will be low as long as the system works as designed; however, handling errors in the system require personnel that have particular expertise in this technology.

Two-dimensional matrix codes applied indirectly through tape attached to the item do not require large investments costs. Computer software, a specialized printer and printable tape will cover the application needs. If a pin marking solution is chosen, additional marking equipment will be needed. The system will require advanced handheld readers that can cost up to $1000 per piece. Central locations should be equipped with several readers to allow for simultaneous operations in each location. Since this system is not automated, there will be considerable labor costs in this solution. Every time a code is read, it will involve direct labor. Labor costs will be lower than in the current solution as the amount of time needed to control each item will be lower. Also, reprinting and replacing damaged codes will require labor.

In the tandem solution, the investment cost for the IUID part will be similar to the IUID solution. The main difference when comparing cost is that the labor cost will be lower as a part of the inventory will be covered by the RFID system. The investment cost for the RFID part will be lower than in the RFID solution, as the number of antennas will be lower, fewer infrastructural changes will be needed, and conventional RFID tags can be used. Also, the need to replace lost or damaged tags will be smaller.

F. TEST OF RFID ON AN ASSAULT RIFLE

This section covers the experiment that was conducted to determine whether the RFID solution is feasible to manage small arms inventory. The background for the test, the procedures used and the results from the experiment are presented.

1. Test Background

The objective of the test was to find out whether the RFID technology is applicable in a small arms inventory control system. The test utilized experience from ODIN Technology, which had conducted similar tests in 2010. Their results pointed out that tailored tags are needed to achieve good reading results when tagging metal objects. The best performing tag in ODIN Technology's test was therefore present in the portfolio of tags used in this experiment, and the placement of tags on the rifle was determined based on the results from the ODIN Technology tests. Prior to the experiment, several tag producers were contacted by mail or telephone to provide tags for the experiment. They were informed what environment and on what objects the tags were going to be used.

The goal of the test in this thesis was to not to find the optimal or best performing tag available, but to find out what reading range can be expected with a RFID tag attached to an assault rifle. The hypothesis that was tested was the following:

Hypotheses 0: The expected read range with a handheld reader of a RFID tag on small arms is equal to or under thirty centimeters.

Hypotheses 1: The expected read range with a handheld reader of a RFID tag on small arms is over 30 centimeters.

Thirty centimeters was chosen because this is the expected read range of a 2D matrix code with a handheld reader. For the tags that achieved a reading range over thirty centimeters, further tests were conducted to find the maximum reading range achievable with a more powerful interrogator.

2. Conducting the Test

The test was conducted at the Poly GAIT Laboratory at Cal Poly State University in San Luis Obispo, California, on March 18, 2011. The experiment was supported by Professor Tali Freed and one of her research assistants.

a. Hardware Used in the Test

The following tags were included in the test portfolio:

- Tool RFID Anycall Young Tech
- Simply RFID nox-tm4
- TitanTag Smallest

Figure 32. TitanTag Smallest on a Small Arms Replica. Best performer of the ODIN Technology Test.

- Sontec High Temperature Tag G

Figure 33. Sontec High Temperature Tag G on a Small Arms Replica. This Tag Proved to be Very Sensitive to the Orientation of the Tag.

- Xerafy X-series Pico

Figure 34. Xerafy X-series Pico was the Smallest Tag in the Test.

- Xerafy X-series Micro

Figure 35. The Xerafy X-series Micro Tag was too Large to fit on the Optimal Position, but did fit Above the Magazine of the Rifle.

The following weapon was used to replica an HK 416 assault rifle:

- Stag Arms STAG-15 Full Metal M4

The following handheld reader was used to measure whether the reading range exceeded thirty centimeters:

- Motorola Handheld MC9090 R6

The following fixed reader was used to measure the maximum reading range:

- Sirit Infinity510 Cart-Mounted Reader with handheld Poynting Antenna Model Patch-A0025

The following locations were used to conduct the tests:

- Tests with the handheld reader were performed in a Faraday cage

Figure 36. Entrance to the Faraday Cage at Cal Poly; the Cage Blocks all External Static Electricity Fields and Provides a Clean Environment for Testing.

- Tests with the powerful interrogator were conducted outdoors, with no physical obstructions between the tagged item and the antenna

Figure 37. California has a nice environment for Outdoor Testing, Even in March.

b. Test With a Handheld Reader

Step 1: The tag was attached to the rifle on the optimal point based on ODIN Technology tests. Tape was used to physically attach the tag to the rifle. The rifle was laid on a plastic rack in a Faraday cage.

Step 2: By using a handheld reader in different angles to the tag, the maximum distance for a successful read was measured.

Step 3: The tag was rotated 180 degrees to check for orientation sensitivity and step two was repeated.

c. Test With a Fixed Reader

Step 1: The tag was attached to the rifle on the optimal point based on ODIN Technology tests. Tape was used to physically attach the tag to the rifle. The rifle was held by a person with no obstruction between the tag and the antenna. Only the three best performing tags from the handheld test were included in this test.

Step 2: By pointing the antenna towards the tag and moving the weapon towards the antenna, a maximum distance for reading the tag was measured.

d. Test Validity Issues

The test was conducted in an environment screened from outside electronic interference. However, there are some potential validity issues that must be considered, as shown in Table 4. These issues could have affected the results of the test both favorably or unfavorably.

Concern	Comment
Replica rifle might not have the same coating or metal content as the real rifle.	Further testing should be conducted on the actual rifle.
Test only used one type of handheld reader and one type of fixed interrogator.	Finding the optimal reader and antenna requires an independent set of tests.
Tags attached to the weapon with tape, and some tags are too large to fit on the optimal position on the rifle.	Additional tests should be performed with tags sized for the rifle using permanent attachments.
Variability in performance among tags of same type. The tags used might not be 100% representative for the performance of the tag type in general.	Testing with a bigger sample of tags of each type would mitigate this error.

Table 4. Sources of Validity Concern.

3. Test Results

Table 5 shows the results with the handheld reader. For the tags that are mentioned twice the test was conducted on two different tags of the same type from the same producer.

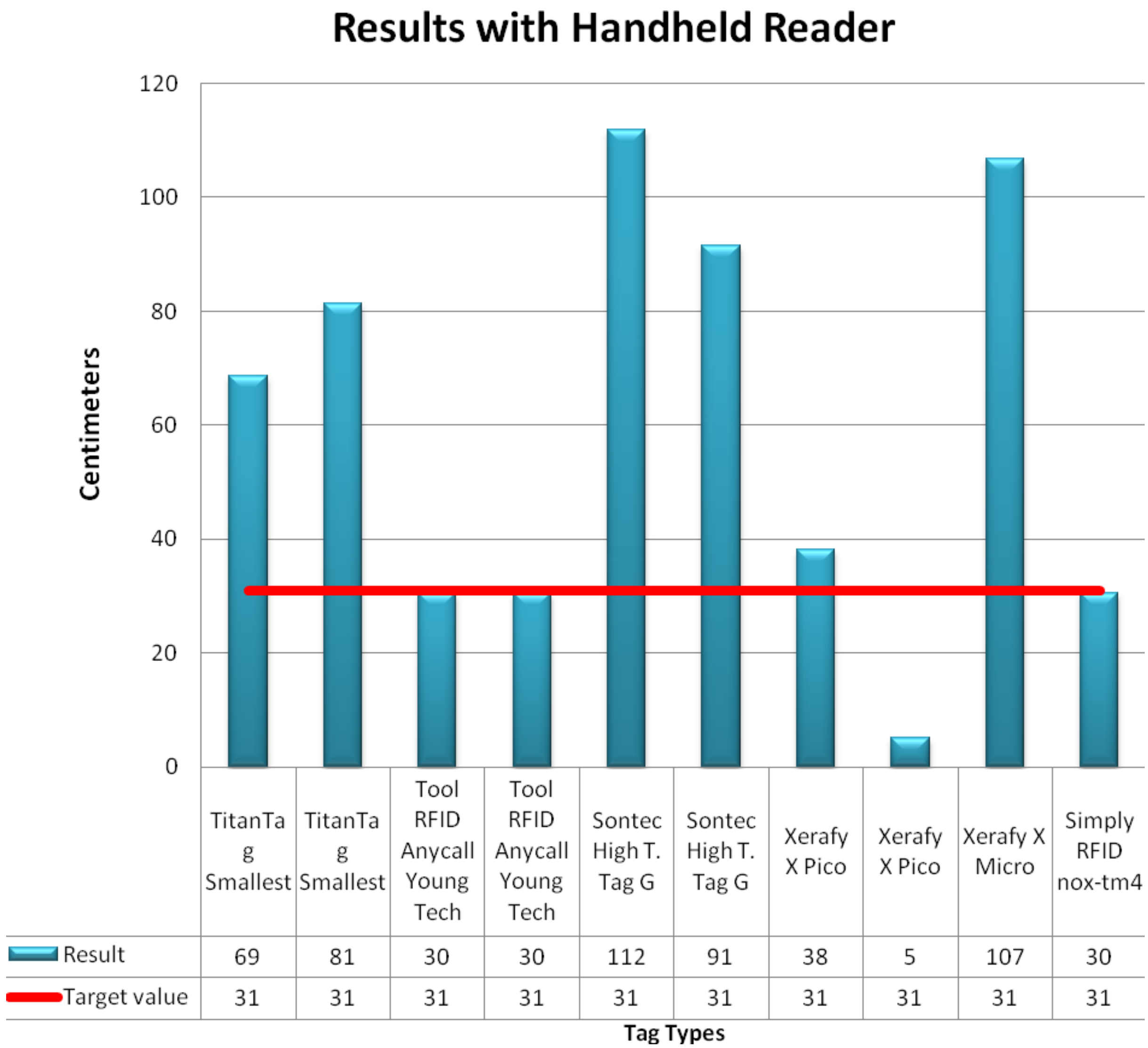

Table 5. Results from the Handheld Reader Tests.

Notes:

- TitanTag Smallest: the best reading orientation is at thirty degrees to the vertical line stretching from the face of the tag.
- Tool RFID Anycall Young Tech: the orientation must be with holes in a vertical line; otherwise reading distance is nine centimeters.
- Sontec High Temperature Tag G: the orientation must be with holes in a vertical line; otherwise reading distance is six centimeters.

For the three best performing tags in the handheld test, the maximum reading distance with a fixed antenna was measured. Table 6 shows the results obtained by the author.

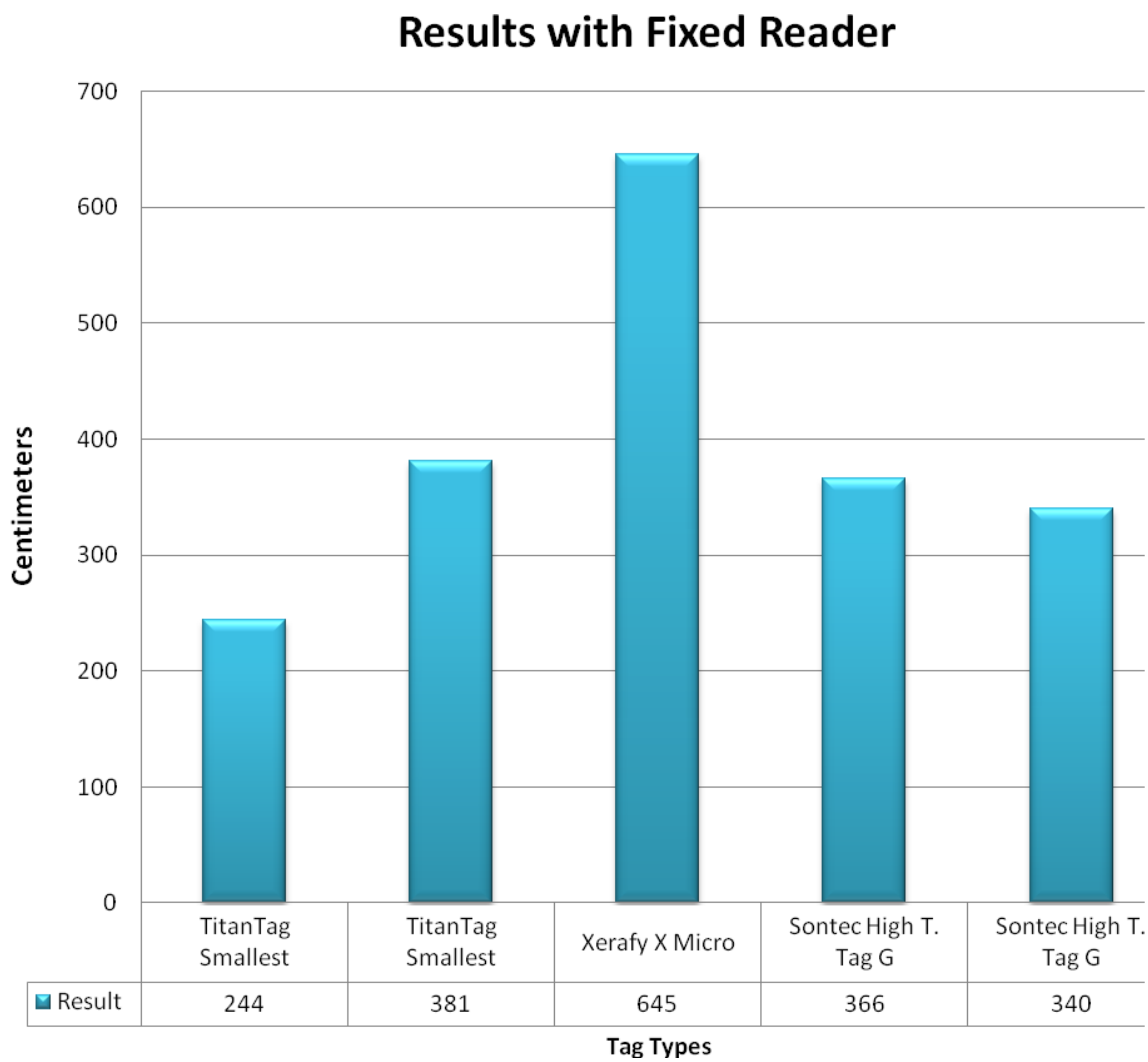

Table 6. Results from the Fixed Antenna Reader Tests.

4. Test Summary

The results from this test support that a tailored RFID tag attached to a rifle will be able to achieve reading distances over thirty centimeters when read with a handheld reader. The test shows that there is big difference among performance of the different types of tags, so thorough testing must be conducted on the actual item before a tag type is chosen for the application. The second part of the test shows that a reading range of over two meters is possible when using a more powerful interrogator. A cart- mounted interrogator, like the one used in this test, will lessen the need for installing several fixed antennas in a storeroom, and thereby lower investment costs and maintenance requirements.

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VI. RECOMMENDATIONS FOR THE NORWEGIAN ARMED FORCES

This part of the thesis summarizes the discussion for each of the previously covered four options; the current solution, RFID solution, IUID solution and the tandem solution. The final recommendation, the tandem solution, is explained in detail, and alterations to the processes due to this solution are described.

In the current solution, no AIT is used in the management of inventory. The major drawbacks with the current solution are that it does not achieve the wanted levels of inventory accuracy and it is very labor intensive and inefficient.

In the RFID solution, RFID tags are attached at the item level to the rifles in the inventory. The test conducted in this thesis showed that the RFID solution is a feasible solution, and when set up and working properly it can achieve a high level of inventory accuracy with low requirements for labor needed in the process. Metallic objects are among the most challenging materials to mark with a RFID tag. Therefore, individual tests and tailoring are required at each location where it is implemented. It may also be questionable whether the results from an automated scan of an inventory can be accepted without a physical count to double-check it. If a physical count is needed to confirm the results from the RFID scans, it means labor savings will decrease. The attachment of the tag to the rifle has not been discussed in this thesis. The weapons will be used in harsh and varying environments. If tags are lost or damaged when the weapons are used, replacing them increases the amount of manual labor needed and lowers the accuracy and trustworthiness of data from the system. Costs for the RFID solution are hard to predict because the solution has to be tailored to each location it is applied. Overall, the uncertainty with the RFID solution increases the risk, and it will be challenging for an organization that has no experience with RFID to be successful with an implementation of RFID tags at the item level on metallic objects.

In the IUID solution, 2D matrix codes are attached to each item using an indirect application method. The IUID solution offers some labor savings compared to the current

solution and increases the accuracy greatly. Durability is closely connected to the application mode that is chosen. Tests have to be conducted to determine the type of code and how the code is attached to the rifle. Handheld readers and specialized printers are the major implementation costs.

In the tandem solution, the benefits from both the RFID and IUID solution can be achieved. The solution is less complex than when RFID is used on an item level and will provide a high level of accuracy and labor savings compared to the current solution. The section below describes the solution that this thesis recommends for the NAF.

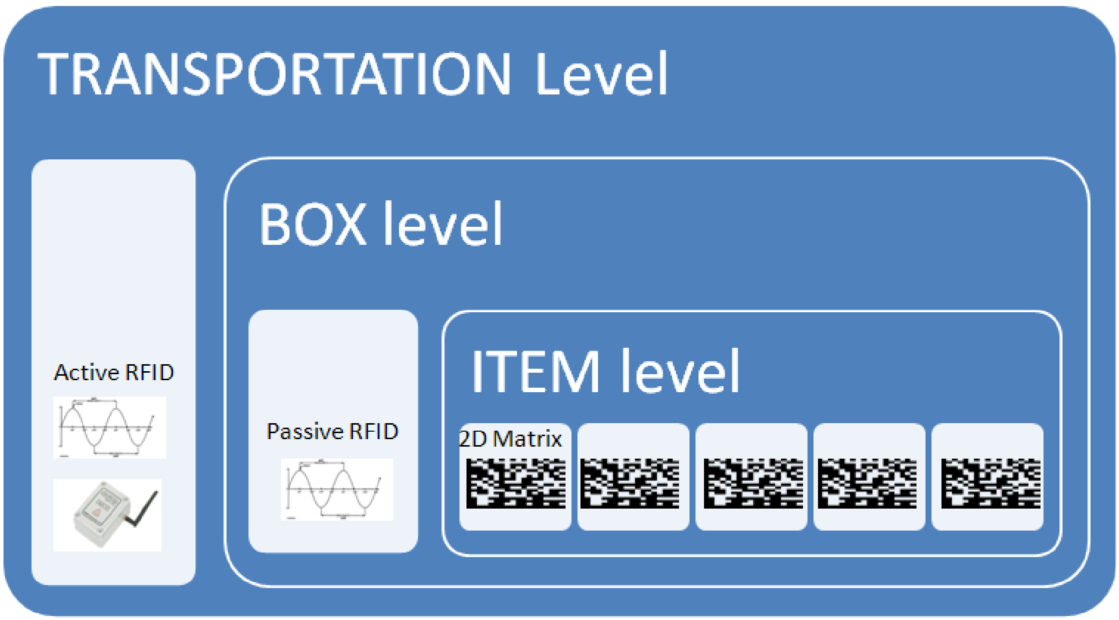

Figure 38. Tandem Solution, the Recommended Solution with AIT Used in Three Different Layers.

On the item level, each rifle is marked with a 2D matrix code that contains information about weapon type, batch number, serial number and any other data required. The code is applied indirectly by tape application to a vital part of the weapon that is easily visible. Codes can be applied at several places to increase both durability and accessibility of the code. Codes that are damaged can easily be reprinted and replaced.

Items that are not planned to be moved within the next period are stored in plastic boxes. The items stored in a box are registered to a programmable and rewritable passive RFID tag that is attached to the box. The box is sealed and checked for content frequently.

When weapons or ammunition are transported, an active RFID tag is programmed according to the specific content and route that is applicable and the tag is attached to the transport vehicle or container that is used. Alterations of processes at the transportation level are covered earlier in this thesis (see Chapter V).

Manually reading and entering of serial numbers is replaced by an automatic process where the 2D matrix code is scanned and automatically updates the ERP system. This prevents errors like assigning the wrong serial number or wrong weapon type to a user and due to this inventory accuracy will improve. Figure 39 shows a flowchart of the process of delivering out weapons using the tandem solution.

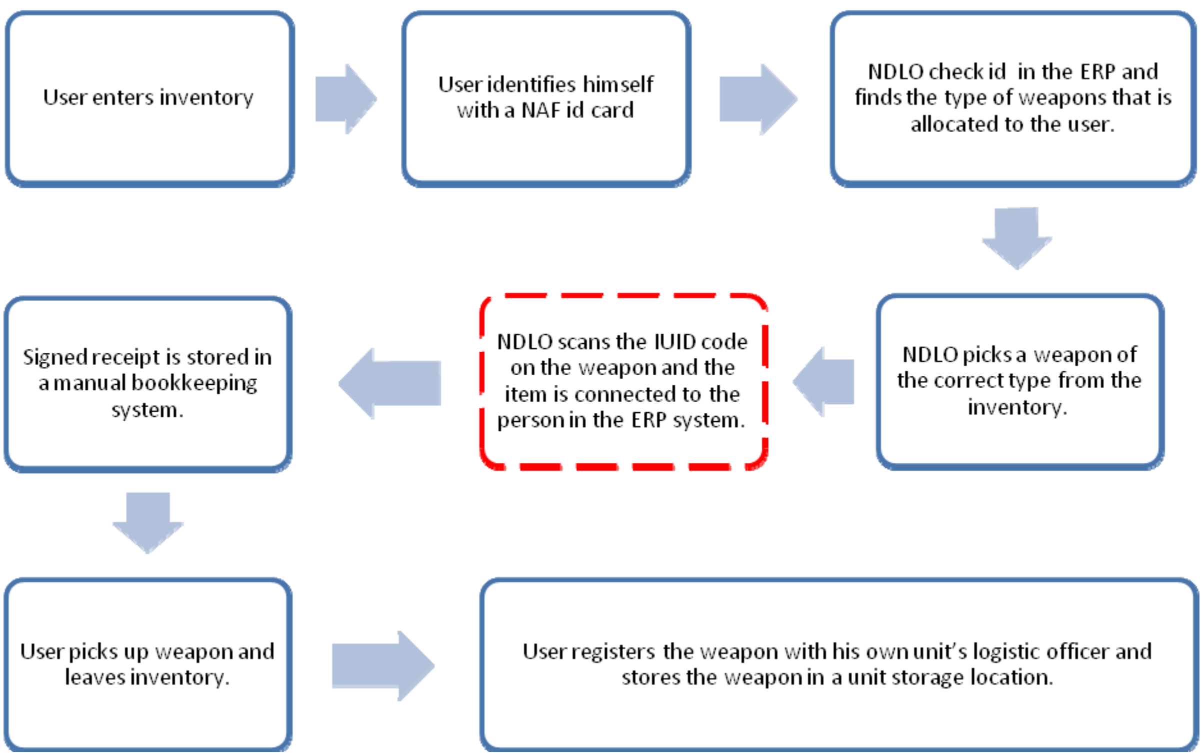

Figure 39. Flowchart of the Delivering Out Weapon Process. The Dotted Box Shows Processes Changed in the Tandem Solution.

Monthly inventory control will be more efficient than with the current solution. Scanning codes increases the accuracy, and by having weapons stored in sealed boxes the number of weapons that need to be manually controlled is lower. Figure 40 shows how the process is preformed in the tandem solution.

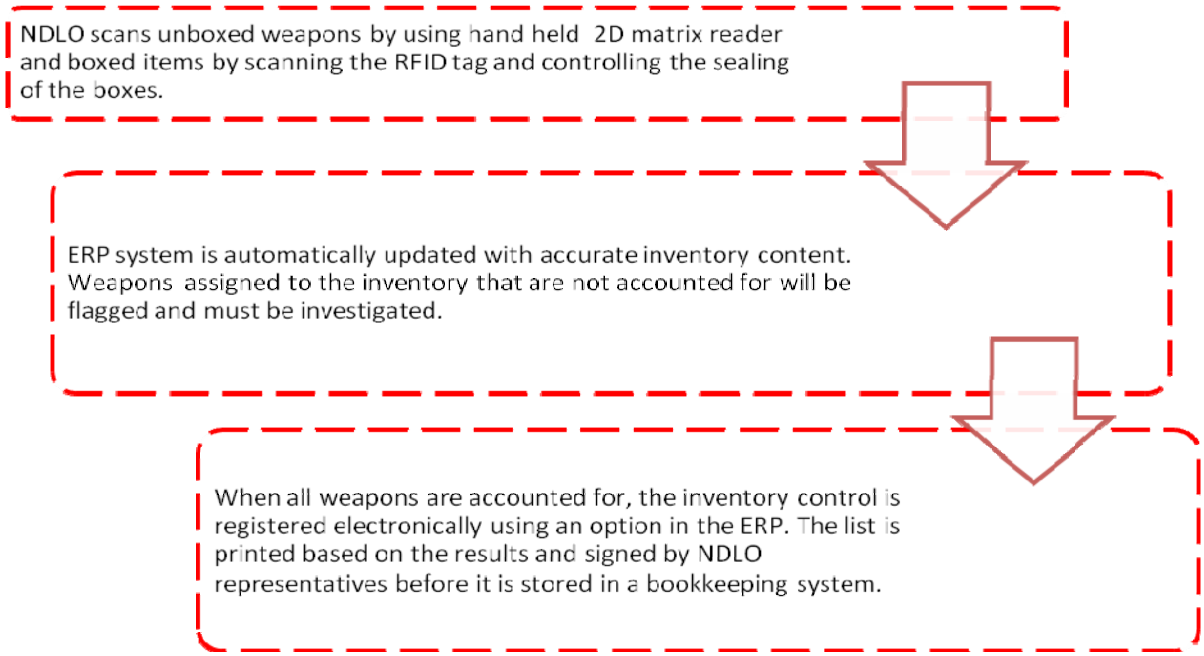

Figure 40. All Phases of the Flowchart of Monthly Inventory Control are Changed in the Tandem Solution.

Scanning codes instead of reading and entering them manually into the system increases the accuracy of the inventory system and prevents errors. Figure 41 shows how the re-signing process is preformed in the tandem solution.

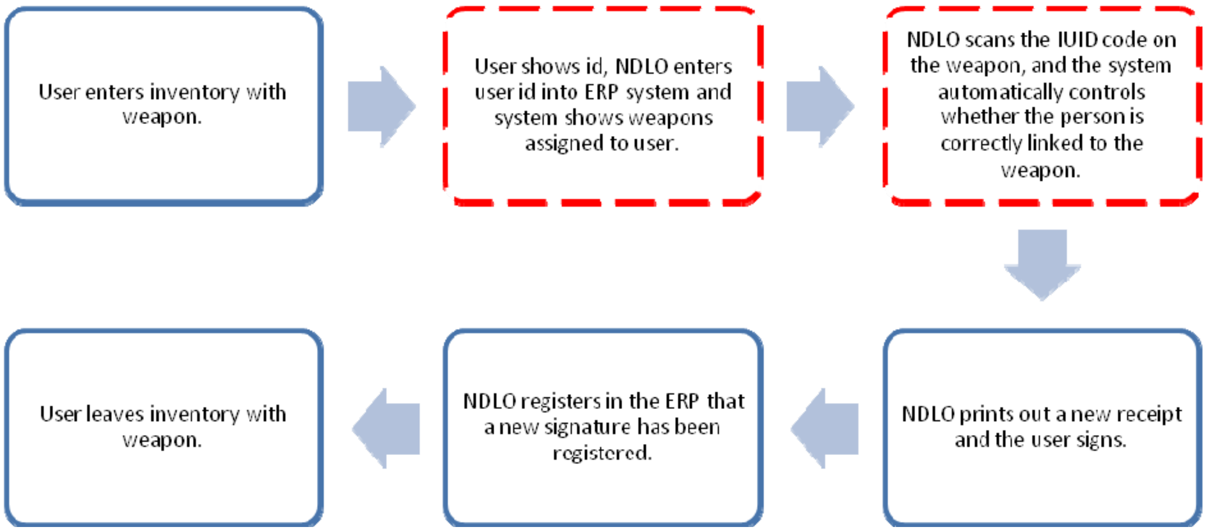

Figure 41. Flowchart of Annual Re-signing of Weapons. Dotted Boxes Show Processes Changed in the Tandem Solution.

All information necessary to implement the tandem solution is not presented in this thesis. A survey of suppliers and laboratory testing of 2D matrix codes and which application option that is to be used must be conducted early. Experience from the U.S. DoD's implementation can be used to shorten the list of options. Then, different types of 2D matrix codes have to be applied and field tested to determine the best suitable code and where it should be placed on the weapon. This test should be conducted by handing marked weapons out to operational units that actually use the weapons. Tests must also be conducted to determine the best suitable RFID tag and interrogators for the box level implementation. Both the IUID readers and the RFID system must be tailored to interact with the ERP system to allow for streamlined information sharing. Finally, a pilot project should be conducted at one of the locations to see how the system performs in day-to-day operations. Alterations that are needed can thereby be detected early, and this will make

the full rollout of the solution easier to accomplish. The critical events in this phase are to ensure that the 2D matrix code that is picked can withstand the environment the weapons are used in, making a system that is able to communicate with the ERP system, and developing a user interface that is easy for the operators to use and understand.

VII. CONCLUSION

AIT has been an important factor in supply chain improvements and in making processes in both retail and industry more efficient over the last couple of decades. AITs, like IUID codes and RFID tags, are data carriers that when used in an information system provides management with more accurate and larger amounts of information than prior. AIT provides a tool that is able to store, communicate and transport large amounts of data over time or distance.

RFID uses radio waves to transmit information from items to the information system, while IUID utilizes visual scanners to achieve the same. RFID is perfectly tailored for items that have high movement velocity or large volumes and can be totally automated. IUID is a development from the successful barcode technology branch and offers high levels of accuracy and redundancy against errors. The end results are the same for both, as they remove the need for interactions of workers and can increase the speed and accuracy of data collection greatly. Some companies are forced into AIT because they are downstream elements of a larger supply chain that require it, while others can make the decision based on their internal needs.

Any organization that looks to improve their inventory management processes or supply chain with an AIT must first define the objective with the implementation. Then, they must analyze the current processes and look at the characteristics of both the items and the environment where the technology will be operating. To know which solution to choose and how to benefit from it, they must invest in knowledge about the different options that are available. Before a solution is implemented, the organization must analyze what it wants to accomplish and how it will use and benefit from collected data.

This is what this thesis has done for the NAF and their AWA project. First, AIT was described to show the benefits and challenges of the different options. The goal was to let the reader understand how the technology works, where it is suited and what is required to make it work. Then the objective was defined; for the NAF the main objective was to increase the inventory accuracy of their small arms inventories. The processes that

affect their inventory were defined and put into descriptive flowcharts. An analysis was conducted on four different options that were tested theoretically to find out how they would perform against the stated objectives and then compared to each other. For the RFID solution, an experiment was conducted to determine whether this is a feasible solution at all.

A recommendation was formed based on the results of this analysis. The tandem solution, which uses IUID technology at an item level, passive RFID at a box level and active RFID when items are transported, was the recommendation. This solution uses the appropriate technologies where they are best suited and offers the best results for an accurate inventory control system with low implementation costs and risks.

Through this implementation, the NAF will gain experience in how to set up, operate and utilize AIT in a limited part of its inventory system. When stakeholders in the organization see the benefits AIT can lead to and knowledge that already exists within the organization, successfully expanding the use of AIT to other processes will be easier to accomplish and further improve inventory and supply chain processes in the NAF.

LIST OF REFERENCES

Active RFID tag with external antenna from Sebine Technologies. Accessed February 16, 2011. http://www.gobizkorea.com/blog/ProductView.do?blogid=sebinetech&id=945515.

Association for Automatic Identification and Mobility. "2D Data Matrix Code." Accessed February 24, 2011. http://www.aimglobal.org/technologies/barcode/2d_symbologies_matrix.asp.

———. "Barcode Scanning."Accessed January 15, 2011. https://www.aimglobal.org/technologies/barcode/barcode_scanning.asp.

———. "Industry Application Table." Accessed January 15, 2011. http://www.aimglobal.org/technologies/barcode/industries_2D.asp.

———. "Stacked Symbologies." Accessed January 15, 2011. https://www.aimglobal.org/technologies/barcode/2d_symbologies_stacked.asp.

———. "UID Case Study: Barrett Firearms Manufacturing, INC." Accessed January 19, 2011. http://www.aimglobal.org/members/news/articlefiles/3450-A2B_Tracking_BFMI-cs.pdf.

Bacheldor, Beth. "Hybrid Tag Includes Active RFID, GPS, Satellite and Sensors." RFID Journal, February 24, 2009.

Bartneck, Norbert, Volcker Klass, and Holger Schoenherr. *Optimizing Processes with RFID and Auto ID.* Publics Publishing, 2009.

Bensman, James. *UID Journal Workbook Volume 1*. UID Journal, 2008.

Boyle, William, and Michael Friedman. "Small Arms UID." DTIC Online Information for the defense community. May 17, 2006.

Dean, Graham. "RFID Weapons and Armoury Management System, Applying the technology to an armoury application and description of a Case Study." Home Office Scientific Development Branch 25/06. 2006.

Department of Defense. *Item Unique Identification, 101*, *The Basics*. January 2006.

Dot Peen application of 2D matrix. Accessed February 24, 2011. http://www.2dmarking.co.uk/Products.htm.

Ferrer, Geraldo, Nicholas Dew, Nicholas, and Uday Apte. "When is RFID right for your service?" Int. J. Production Economics 124. 2010.

Financial and Economic Rata Relating to NATO Defence. NATO. Accessed January 17, 2011. http://www.nato.int/nato_static/assets/pdf/pdf_2010_06/20100610_PR_CP_2010_078.pdf.

Fixed Conveyer Barcode Scanner. Accessed February 24, 2011. http://www.barcodemakersoftware.com/images/view/2426/Conveyor%20Fixed%20Barcode%20Scanner.html.

FLO Systemstyring. "Programdokument 2 for Forbedret forvaltning av attraktive vaapen og ammunisjon i Forsvaret AVA." June 01, 2008.

Garfinkel, Simon, Beth Rosenberg. *RFID, Applications, Security, and Privacy*. Pearson Education Inc. 2006.

Handheld 2D matrix scanner from Hawkeye. Accessed February 24, 2011. http://www.microscan.com/en-us/products/Handheld-Barcode-Scanners-and-Imagers/HawkEye-45T-Handheld-Imager-with-Integrated-Display.aspx.

Harris, Rico R., Dale F. Locklar, and Luke R. Wright. "Feasibility of Radio Frequency Identification (RFID) and Item Unique Identification (IUID) in the Marine Corps Small Arms Weapons Tracking System." MBA Professional Report, Naval Postgraduate School, 2008.

Jacobsen, Morten. "Retningslinjer for sikring av attraktive vaapen og ammunisjonsartikler (AVA) i Forsvaret." May 21, 2008.

Jolly, INC. "Data Matrix 2D Barcode." Accessed January 18, 2011. http://www.jollytech.com/support/knowledge_center/barcode_symbologies/data_matrix.php.

Lahiri, Sandip. *RFID Sourcebook*. IMB Press. 2006.

Linear Barcode. Accessed February 24, 2011. http://www.aimglobal.org/technologies/barcode/linear_symbologies.asp.

Lozano-Nieto, Albert. *RFID Design Fundamentals and Applications*. CRC Press, 2011.

Maloni, Michael. and Frank DeWolf. "Understanding Radio Frequency Identification (RFID) and Its Impact on the Supply Chain." 2006.

Manufacturing Digital. “How Datamatrix Barcoding could benefit the pharmaceuticals industry.” Accessed January 24, 2011. http://www.manufacturingdigital.com/blogs/editor/how-datamatrix-barcoding-could-benefit-pharmaceuticals-industry.

Michael, Katina and M. G. Michael. *Innovative Automatic Identification and Location-Based Services*. IGI Global. 2009.

Ng, Mun L., S. Kin Leong, Peter H. Cole. “RFID Tags for Metallic Object Identification.” Taylor & Francis Group. 2007.

Ngai, E. W. T., Karen Moon, Fredrik Riggins, and Candace Yi. “RFID research: An academic literature review (1995–2005) and future research directions.” Int. J. Production Economics 112. 2008.

Noren, Terje. “Prosjektforslag program AVA.” December 4, 2008.

Norwegian Armed Forces. “Norwegian Defence Facts and Figures 2010.” Accessed January 28, 2011. http://www.mil.no/multimedia/archive/00141/Fakta2010_engelsk_141161a.pdf.

Odin Technologies. “Automated Weapons Tracking – Easy Arms TM.” Document sent to author. February 10, 2011.

———. “Give your weapons a voice.” Document sent to author. February 10, 2011.

Passive RFID tag embedded in label. Accessed February 23 2011. http://www2.cpttm.org.mo/cyberlab/rfid/intro.html.en.

Passive RFID tag with antenna. Accessed February 23, 2011. http://www.consumerwarningnetwork.com/wp-content/uploads/2008/11/rfid_tag_blue_security.jpg.

Reading range of RFID antenna from AnteTec. Accessed February 27, 2011. http://www.antetec.com/news/2010/03/25-415.html.

SAP United States. “SAP Solutions for Auto-ID and Item Serialization.” Accessed February 23, 2011. http://www.sap.com/solutions/auto-id/brochures/index.epx.

Stacked Barcode. Accessed February 24, 2011. http://www.aimglobal.org/technologies/barcode/2d_symbologies_stacked.asp.

Sweeney II, Patrick J. *RFID for Dummies*. Wiley Publishing, 2005.

Wavelength in an Electro Magnetic Wave. Accessed February 14, 2011. http://www.tpub.com/content/aerographer/14271/css/14271_55.htm.

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